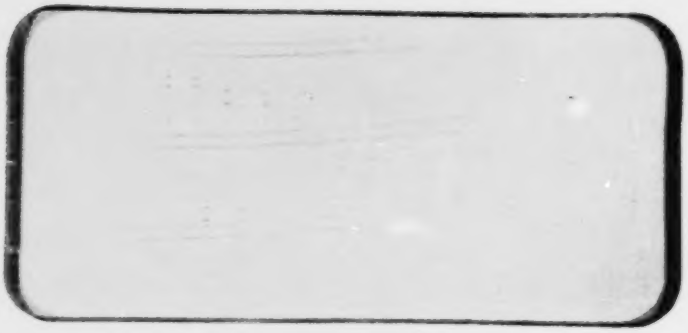
Technical Report



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COMPUTER AIDED DERATING ASSESSMENT OF OIL-DESIGNED WALL-FIRED UTILITY BOILERS USING COAL-WATER SLURRY FUEL

FINAL REPORT

BY

BABCOCK & WILCOX CANADA

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1.0 INTRODUCTION

1.1 Background

The search for alternatives to fuel oil has led to the development of coal/oil mixture and coal/water slurry fuels. The coal/water fuels have the attractive feature of totally eliminating oil as a main fuel, but the unit derations resulting from their use in oil capable boiler designs may limit their usefulness. A recent study conducted by the Electric Power Research Institute [1], evaluated the economic retrofit potential of a number of boiler types to coal/oil mixture firing. The results of this study indicated that, in general, the cost savings to be realized (at 1981 oil prices) in a conversion from oil to coal/oil mixture firing, were expected to be marginal.

The promising aspects of coal/water slurries as fuels (CWF) led to an EPRI project [2], (No.1895), to develop and demonstrate a highly-loaded coal/water slurry (up to 70% coal by wt.) as a replacement for oil. This work was primarily concerned with developing and costing slurry production methods and establishing the ignition and combustion characteristics of coal/water slurries.

1.1 Backgound - Cont'd.

As the study of highly-loaded coal/water slurries progresses, increased attention is being focused upon detailed investigation of existing oil-designed utility steam generators for conversion to CWF. This study is part of a new initiative prompted by the 1980 Canadian National Energy Program.

Specifically, this study is aimed at evaluating typical wall fired oil capable designed Utility Boilers of the size and style found in Eastern Canada to determinethe expected derating effects of CWF firing.

A second similar report addressing derating effects on oil capable corner fired Utility Boilers is in progress.

1.2 Effects of CWF Combustion on Oil-Designed Boilers

As a result of coal's slower combustion kinetics and the presence of ash in coal, boilers designed for coal and CWF firing must be larger (with more open convective surface spacing) than those designed for oil. The following design features characterize a coal-designed boiler [3];

1. Relatively large furnace. This provides sufficient time during combustion to ensure good char burn-out and hence good efficiency of combustion. The furnace must also have adequate radiant heat transfer surface to promote cooling of the molten ash in the flue gas before it reaches the convection heat transfer surface at the furnace exit.

2. Ample burner spacing. Sufficient burner centre-line spacing and burner to water cooled surface spacing must be provided to limit furnace slagging to acceptable limits.

3. Wider convection surface spacing. Sufficient spacing must be provided to eliminate slag bridging and ensure reasonable gas velocities through the convective sections.

1.2 Effects of CWF Combustion on Oil-Designed Boilers - Cont'd.

4. Hopper bottom slope must be great enough to ensure ash and slag flow into ash pit as well as reduce the chance of damage to the pressure parts from slag falls. Hopper throat must be larger than an oil-designed unit to permit ash and slag to drop to ash pit.

5. Sootblowing capability in both the furnace and convection passes.

The presence of additional moisture in CWF will affect the boiler performance in a number of ways. The need to evaporate this additional moisture prior to combustion of the coal will reduce the flame temperature, decrease the unit's fuel efficiency and contribute to poorer ignition stability. These effects will require higher combustion air temperature,more fuel input for a given output,and burner equipment designed specifically to obtain flame stability and turndown on CWF.

1.2 Effects of CWF Combustion on Oil-Designed Boilers - Cont'd.

Firing pulverized coal or CWF will result in slag deposits on the furnace walls. Due to the relatively low thermal conductivity of this slag, the furnace wall tubes will be partially insulated. This results in decreased radiative furnace heat absorption, increased furnace exit gas temperature and increased convection pass heat absorption. This may result in steam temperature unbalances between secondary superheater and reheater (on units with reheat) and excessive spray quantities to control superheater steam temperature. Superheater and reheater tube metal temperature limits may be exceeded on some designs.

The presence of ash in the flue gas resulting from firing P.C. or CWF will contribute to erosion and limit allowable flue gas velocities through convective surfaces.

CWF firing will produce flue gas flows slightly higher than those from P.C. firing as a result of reduced fuel efficiency. The above characteristics of CWF will result in deration of oil designed boilers.

1.3 Study Objectives & Limitations

The objective of this study was to determine the expected unit deration of Canadian oil-designed utility boilers to fire both P.C. and CWF. Two typical boiler styles, the B&W El Paso style and the B&W Carolina style, were investigated. One large unit (1215 Mlbs/hr of steam) and one small unit (700 Mlbs/hr of steam) were analyzed for their expected derations to fire the following fuels;

i) high ash pulverized coal (8% ash)
ii) low ash pulverized coal (3% ash)
iii) high ash CWF (6.3% ash)
iv) low ash CWF (2.1% ash)

Although the results of this investigation reasonably predict the expected deration of typical Canadian oil-designed wall fired boilers, it must be stressed that a detailed site-specific deration study must be done before any decision is made concerning conversion of an existing boiler.

1.4 Assumptions

1.4.1 Boiler

1. Both the Carolina and the El Paso style boilers were designed to Babcock & Wilcox current design standards. It must be realized that the El Paso style boiler was developed primarily for oil and gas fired applications and, as such, will be an inherently "tighter" design than the Carolina style, which is primarily used for PC firing. This is particularly true in the smaller unit sizes.

2. The large El Paso design controls reheat steam exit temperature by using burner level input modulation, whereas the large Carolina design uses gas recirculation.

3. The unit deration calculations are based upon making no changes to the boiler pressure parts; although a qualitative assessment is made on the possible improvement in maximum attainable load if minor pressure part modifications were to be made.

4. No consideration has been given in this report to any implications on the boiler structural steel from conversion to CWF firing.

1.4.1 Boiler - Cont'd.

5. No modifications to the burners, associated fuel train or boiler controls, have been considered.

6. Necessary changes to handle ash resulting from CWF firing have not been considered.

7. The superheat/reheat control range assumed for designing the oil fired units was 100 to 60 percent.

8. The study was limited to consideration of the following equipment;

   i) boiler proper
   ii) fans
   iii) regenerative air preheaters
   iv) sootblowers

1.4.2 Fuel

1. It was assumed that slurrying would have no effect on the ash fusion temperature or slagging/fouling tendencies of ash chemistry of the parent coal.

2. It was further assumed that beneficiation of the coal would have no effect on the ultimate analysis of the coal ash during PC or CWF firing.

3. All study results are based upon fuels specified by CANMET and summarized in Section 5.0.

B&W and CANMET have agreed that the study should proceed based on the above assumptions. For further discussion refer to Section 6 of the report.

1.4.3 Performance

1. In view of the fact that there is little full scale operating data available on units firing CWF, the following parent PC design criteria has been used for CWF firing unit derations;

   a) heat input/burner
   b) burner zone heat release rate
   c) plan area heat release rate
   d) furnace exit gas temperature
   e) furnace volumetric liberation rate
   f) flue gas velocity
   g) allowable tube spacing vs. gas temperature
   h) excess air quantities
   i) surface cleanliness factors

Laboratory testing indicates some coal/water slurries have characteristics which vary greatly from parent P.C. (i.e. changed ash IDT, larger ash particle size etc.). The slurry used for the study is reported to have characteristics similar to its parent P.C. [5]

1.4.3 Performance - Cont'd.

2. Based upon past Babcock & Wilcox experience with firing coal/water slurries the minimum secondary air temperature for stable combustion with this particular CWF is expected to be approximately 500 deg.F.

3. It was assumed that reducing the ash content of the coal would greatly reduce the erosion potential of the resulting ash and therefore erosion barriers would not be necessary up to the flue gas velocity limit of 65 ft. per second. For high ash coal, erosion barriers were used for gas velocities between 50 and 65 ft. per second.

4. No consideration has been given to the effect of the atomizing medium (probably air) used during CWF firing on the performance of the units.

5. The unit performance for CWF firing was determined at the maximum attainable boiler loads. No part load performance for CWF firing was considered.

2.0 EXECUTIVE SUMMARY

In September 1982, B&W Canada contracted with the Dept. of Energy Mines and Resources through CANMET/CCRL to study the derating effect of firing high ash and low ash pulverized coal and coal/water slurry fuel (CWF) on oil capable wall fired boiler designs. Two boiler styles and capacities were studied:

i) 60 MW (e) B&W type El Paso design

ii) 200 MW (e) B&W type El Paso design

iii) 60 MW (e) B&W type Carolina design

iv) 200 MW (e) B&W type Carolina design

An oil capable wall fired boiler was designed for each style and megawatt range. Section 3.0 describes B&W's computer aided detailed design approach. The heating surface and furnace arrangements were designed to meet current B&W allowable design limits. This approach was taken to produce a design which was not site specific and would be applicable to operating boilers.

2.0 EXCUTIVE SUMMARY - Cont'd.

The following design criteria were reviewed for each boiler:

(a) heat input/burner
(b) burner zone heat release rate
(c) plan area heat release rate
(d) furnace exit gas temperature
(e) furnace volumetric liberation rate
(f) flue gas velocity
(g) allowable tube spacing vs. gas temperature
(h) excess air quantities
(i) surface cleanliness factors
(j) superheat/reheat steam temperatures

To verify our approach, all existing B&W El Paso and Carolina style boilers in the Maritimes were reviewed. It was determined that these units have design parameters which are in the range of the parameters used in the study boilers.

The maximum design limits for each of the above parameters are well established for oil, gas and pulverized coal. These limits are determined theoretically and from years of operating experience.

2.0 EXECUTIVE SUMMARY - Cont'd.

Since there is little full scale operating experience available on CWF, the present PC design limits were applied to the CWF for most parameters. Refer to Section 1.4.3 of the report for a detailed breakdown of the performance parameters.

The maximum attainable boiler loads for each boiler model for PC and CWF firing are summarized in Figures 2.1 to 2.4. The major boiler load limiting parameters were furnace exit gas temperature, flue gas velocity and flue gas temperature vs. tube side spacing. The unit deration calculations were based upon making no changes to the boiler pressure parts although a qualitative assessment is made on the possible improvement in maximum attainable load if pressure part modifications were to be made.

No consideration has been given in this report to structural steel revisions, ash handling revisions, fuel train revision, or boiler controls revisions,required for firing PC or CWF.

2.0 EXECUTIVE SUMMARY - Cont'd.

The study was limited to consideration of the following;

i) boiler proper
ii) fans
iii) regenerative airheaters
iv) sootblowers

In order to fully understand the derating effect of each parameter, the design philosophy of each boiler style must be understood.

2.1 El Paso Design

The El Paso style boiler design was developed primarily for oil and gas firing. The allowable flue gas velocities in the convection tube banks are much higher on oil and gas than on coal. It was, therefore, feasible to place all of the superheat, reheat, and economizer surface above the furnace within the same plan area as the furnace. The higher allowable velocities for oil and gas firing permit tight tube sidespacing, which increases heat transfer and reduces overall heating surface requirements.

2.1 El Paso Design - Cont'd.

One of the major driving forces in any design is cost. For oil and gas firing, the EL Paso arrangement is very cost effective. However, convection surface adjustment for future PC or CWF firing is difficult due to the compact arrangement of superheat/reheat tube banks, and their wall support design. (Refer to Section 4, Fig. 4.2). It is obvious that there is little room for surface adjustment on this style of boiler.

2.2 Carolina Design

When designing a boiler for coal firing, the allowable flue gas velocities and temperatures in the convection banks are lower than for oil and gas fired units. These limits are determined by analysing the quantity and composition of the ash in the coal, and determining its slagging and fouling potential (Refer to Section 5 for definition of slagging and fouling).

2.2 Carolina Design - Cont'd.

Lower allowable velocities and temperatures reduces the heat transfer rates and requires the use of increased heating surface. The Carolina style boiler was designed as an effective means of hanging large quantities of wide spaced heating surface above the furnace cavity. (Refer to Section 4, Fig. 4.4). The El Paso arrangement cannot easily accomodate this requirement since all of the convective heating surface is contained within the furnace plan area.

2.3 Deration Evaluation

Figures 2.1 to 2.4 identify the maximum derations of each unit when firing high ash and low ash PC, and high ash and low ash CWF. Fig.2.1 identifies the maximum deration and the design parameter which determine the deration level. Fig. 2.2 is a summary of the deration effects of gas velocity limits on each unit. Fig. 2.3 is a summary of the deration effects of FEGT limits on each unit. Fig. 2.4 is a summary of the deration effects of gas temperature vs. tube side spacing on each unit.

Section 7.0 describes in detail the deration parameters affecting each boiler size in order of priority.

2.3.1 Small Boiler Design

When considering Figure 2.1 it is noted that the small El Paso model is the most severely derated. The maximum attainable load of 41% on CWF firing is determined by the maximum allowable flue gas temperature leaving the furnace and entering the 9 inch sidespaced superheater banks. The Carolina design for oil firing is more conservative than the El Paso design in the small boiler range. This conservatism is a function of furnace heating surface. The furnace dimensions on the small Carolina are constrained by burner clearance requirements and not heat input. This makes the furnace exit gas temperature on oil firing 180^{o}F lower on the small Carolina boiler compared to the small El Paso boiler. Consequently, the maximum attainable load on CWF on the small Carolina boiler is 60%. This restriction is determined by the maximum allowable gas temperature entering the 4 inch spaced horizontal primary superheat banks in the downpass of the boiler.

2.3.2 Large Boiler Design

The Large El Paso design has a maximum allowable load of 53% on high ash CWF. This is a gas velocity restriction imposed by the primary superheater banks at the top of the downpass. Referring to Section 7, Fig. 7.6, the next restriction is 63% load based on maximum allowable FEGT. The Large Carolina boiler is severely restricted by gas temperature limitations entering the first bank of reheat tubes. Referring to Fig. 7.15, the next restriction is 67% load based on maximum allowable FEGT.

When reviewing Figures 2.1 to 2.4, it must be emphasized that application of the deration results to existing boilers may not be valid due to site specific factors. Although there are standard maximum design parameters which must be adhered to for each boiler design, there is wide latitude regarding surface placement and spacing. The Large Carolina designed for this study is representative of those existing in the Maritimes, however, if the reheat banks had wider spacing, the Large Carolina would suffer approximately the same deration as the large El Paso design. Fig. 2.3 is perhaps the most accurate representation of the trend in deration for the four boiler styles studied.

2.3.2 Large Boiler Design - Cont'd.

The spacing and arrangement of convective heating surface can change this trend, as witnessed in this study (Fig. 2.1).

2.4 Field Modifications

A major concern when firing CWF is to limit the flue gas temperature entering the convective heat transfer surface to below the ash fusion temperature. One method of achieving this is to limit heat input to the furnace, (i.e.derate the boiler). Some reduction in flue gas temperature can be achieved by the use of gas tempering at the furnace exit plane. This method is only available on units with gas recirculation fans. The installation of additional furnace heating surface (wingwalls) is another method available for reduction of furnace exit gas temperatures.

If the load limiting performance criteria is flue gas velocity, or gas temperature vs. side spacing, the tube spacing can be altered by removing alternate tube rows or replacing entire banks of tubes. Section 9 of the report address each unit in detail.

2.5 Auxiliary Equipment

In all cases, firing PC or CWF requires the use of an ID Fan. On the small unit designs this will require the addition of required gas flues and fan. The oil capable FD Fans would be suitable for derated firing of PC or CWF on all units studied.

The gas recirculation fan on the large Carolina will be adequate for CWF firing.

The regenerative airheater on the small design El Paso and Carolina boiler is suitable for PC and CWF firing. The airheater on the large boilers generates marginal air temperatures to the boiler. These units require the use of a steam coil airheater to increase air temperature and for cold end temperature corrosion protection.

All four units require the use of additional soot-blowers for firing PC or CWF. Refer to Section 8.0 for a detailed evaluation of auxiliary equipment performance.

2.6 Conclusions

The deration figures generated by this study are dependent on the fuel characteristics and boiler arrangements studied.

Laboratory testing has revealed variations in CWF properties depending on the type of slurrying agents used in its preparation. Each CWF designated for use in a boiler conversion should be analysed to determine its ash viscosity profile and ash fusion temperature. These values have a large influence on the amount of boiler deration required. Incorrect assumptions in this area could render any study meaningless.

In addition, each boiler design will have site specific factors which make it unique. The boiler in question may have a furnace size which is liberal or conservative. This also applies to convective surface arrangement and quantity of air preheater heating surface.

It is, therefore, necessary that a site specific study be performed on any boiler considered for conversion from oil to PC or CWF.

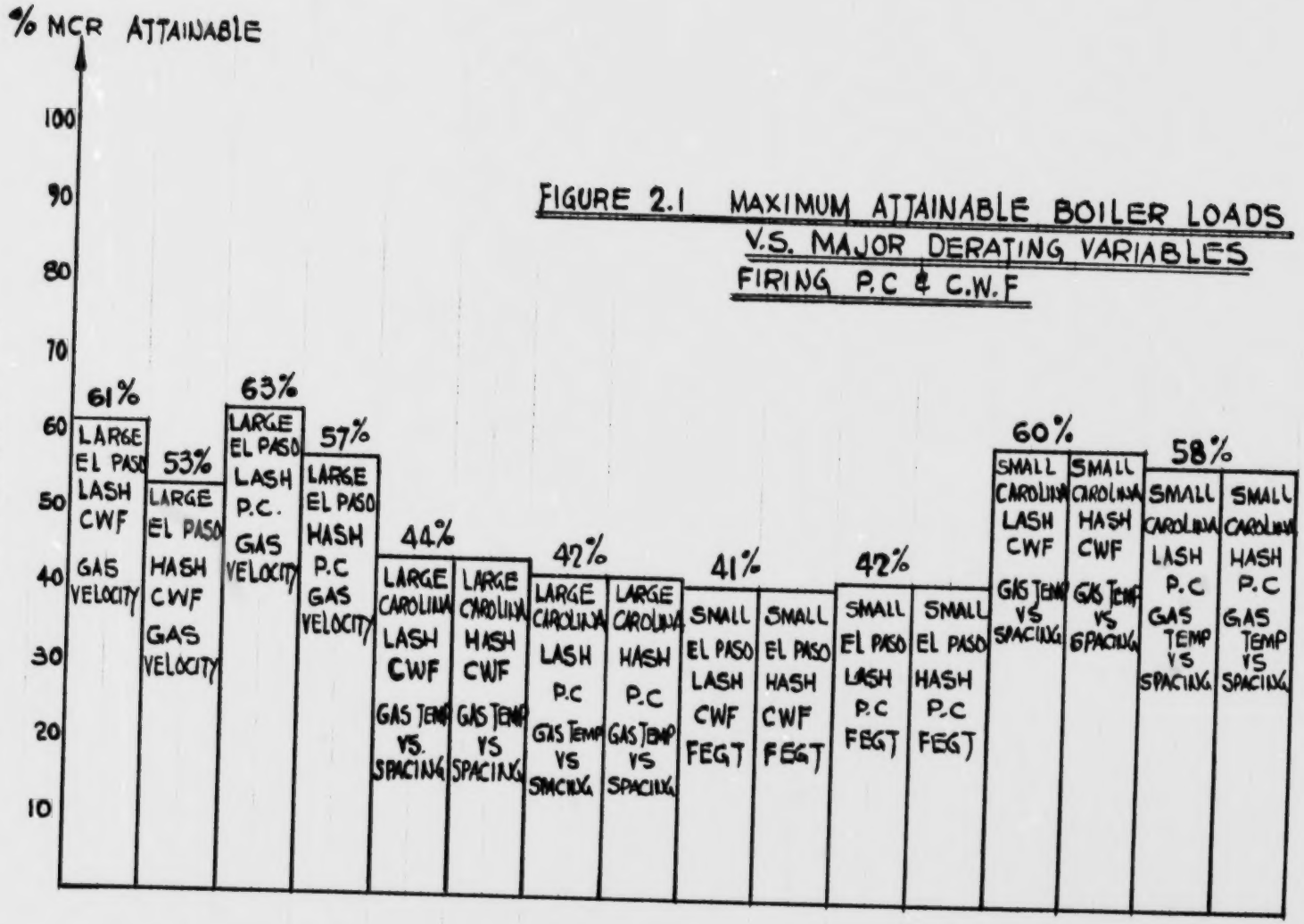


FIGURE 2.1 MAXIMUM ATTAINABLE BOILER LOADS V.S. MAJOR DERATING VARIABLES FIRING P.C & C.W.F

LASH = LOW ASH
HASH = HIGH ASH
FEGT = FURNACE EXIT GAS TEMPERATURE

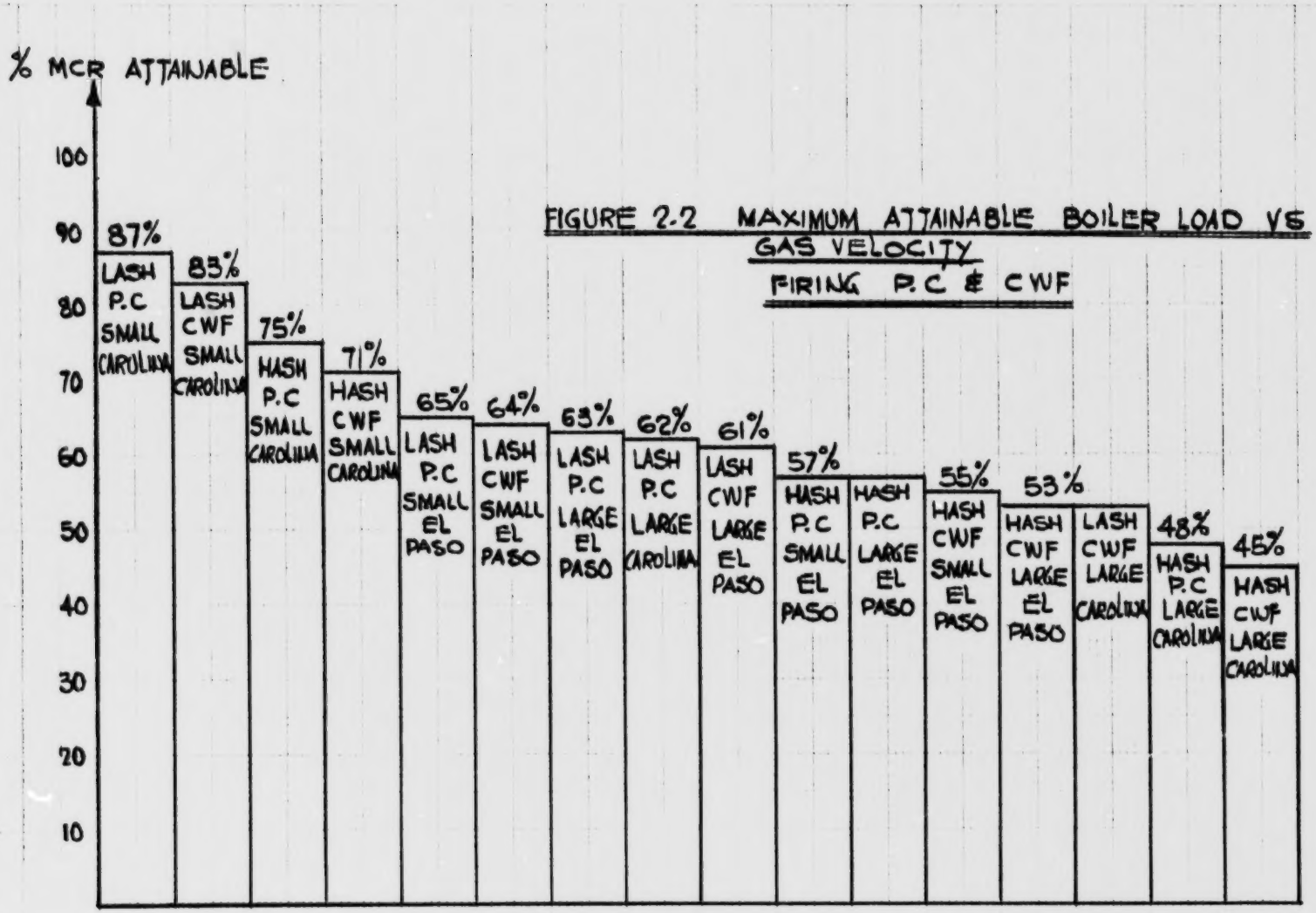


FIGURE 2.2 MAXIMUM ATTAINABLE BOILER LOAD VS GAS VELOCITY FIRING P.C & CWF

LASH = LOW ASH
HASH = HIGH ASH

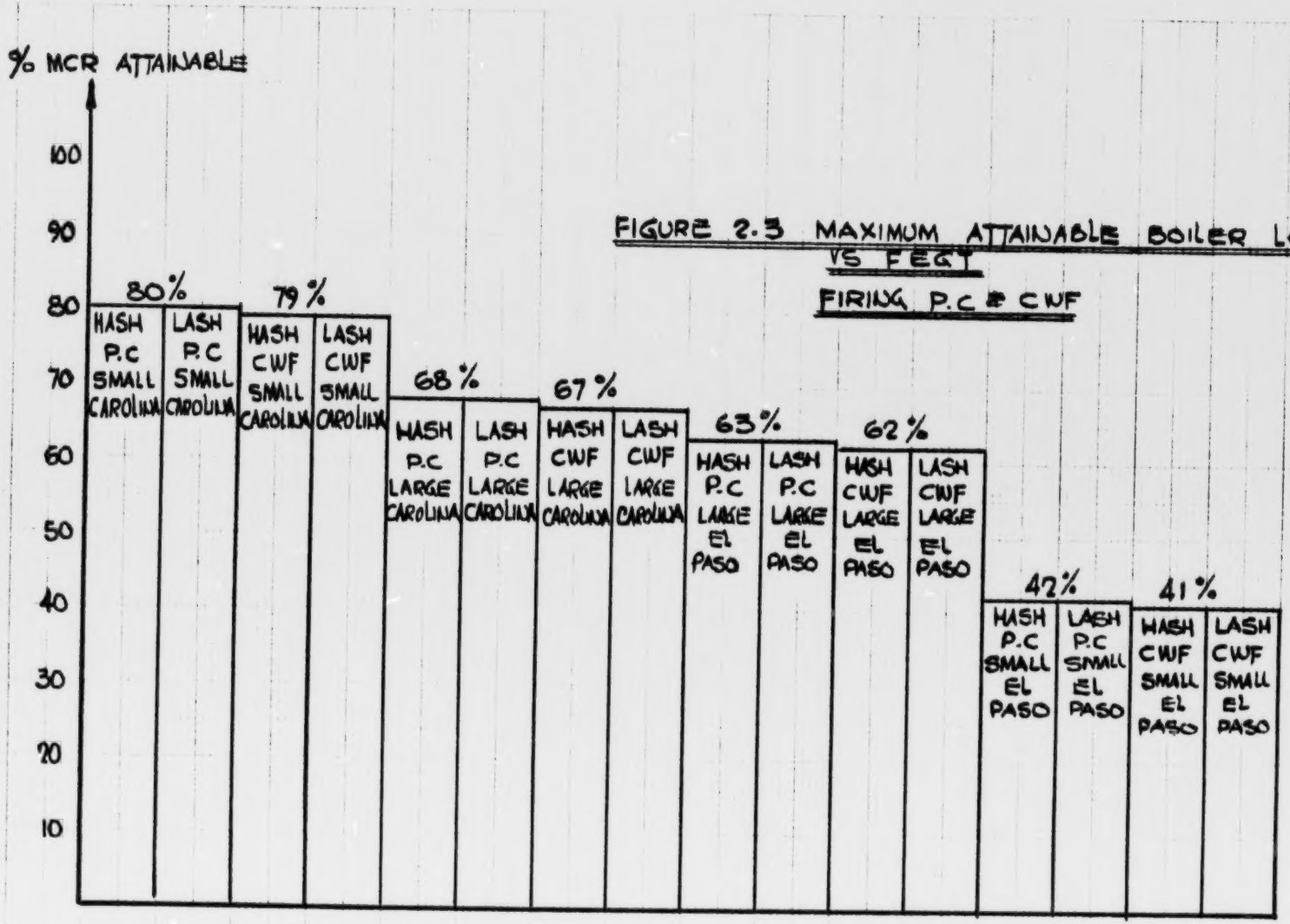


FIGURE 2.3 MAXIMUM ATTAINABLE BOILER LOAD VS FEGT FIRING P.C & CWF

LASH = LOW ASH
HASH = HIGH ASH
FEGT = FURNACE EXIT GAS TEMPERATURE

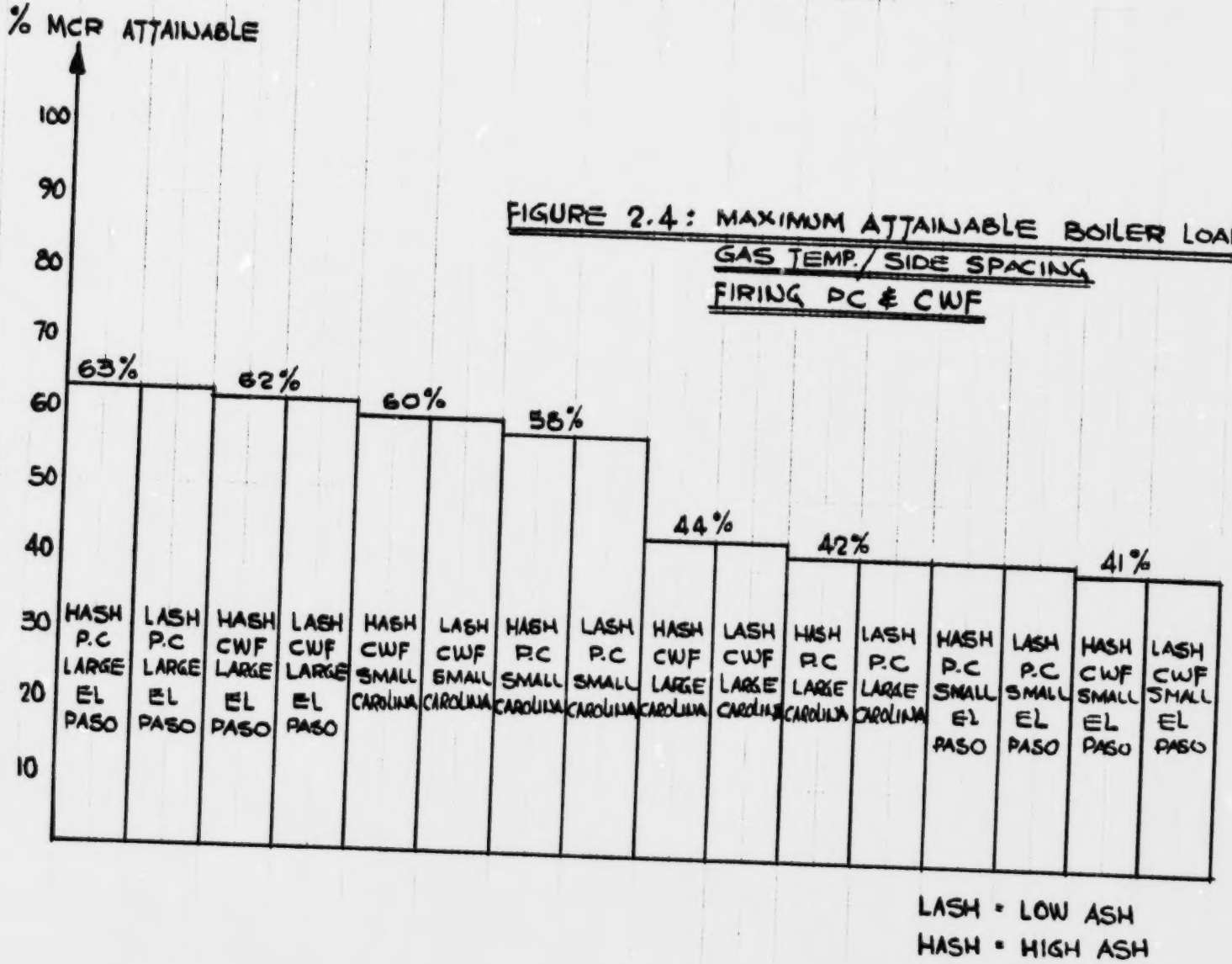


FIGURE 2.4: MAXIMUM ATTAINABLE BOILER LOAD VS GAS TEMP./SIDE SPACING FIRING PC & CWF

3.0 STUDY APPROACH

3.1 General

Four oil-fired units were selected that represent typical B&W Carolina and El Paso style boilers for 700,000 and 1,215,000 lb/hr steam flow capability. The full load steam conditions used are shown in Table 3.1

In the performance analysis of these boilers for the different fuels (oil, pulverized coal, and coal/water slurry) two computer models developed by B&W were used; the multiple zone furnace model and the convection pass model. Experience gained during coal/water slurry investigations at the B&W Alliance Research Centre and literature published by other researchers was used to establish performance parameter limits for CWF firing.

Heat transfer in a boiler is extremely complex since all principal mechanisms of heat transfer occur simultaneously. The computer model must account for intersolid radiation between solid particles in suspension and tubes and refractory materials; non-luminous gas radiation from combustion products, convection from the furnace gases to the tube banks, and conduction through ash deposits on tubes.

3.1 General - Cont'd.

Babcock & Wilcox has developed computer models to combine these mechanisms with empirical data compiled from operating experience; both for the furnace zone and the convection pass.

	Small Unit	Large Unit	Units
Secondary Superheater Outlet			
- Flow	700	1215	Mlbs/hr.
- Pressure	1313	1959	PSIG
- Temperature	960	1005	^{o}F
Reheat Outlet			
- Flow	-	1035	Mlbs/hr.
- Pressure	-	376	PSIG
- Temperature	-	1005	^{o}F
Feedwater			
- Flow	700	1276	Mlbs/hr.
- Pressure	1445	2115	PSIG
- Temperature	440	446	^{o}F
Drum Operating Pressure	1428	2084	PSIG

Table 3.1: Steam Conditons

3.1.1 Multiple Zone Furnace Model

This computer model performs combustion calculations. Based on a known boiler output, the unit efficiency and total input is determined. Using this data the computer calculates the furnace exit gas temperature. The results of these calculations provide the inputs necessary for the convection pass model.

In determining furnace absorption rates (for detailed furnace exit gas temperature calculations) the model uses a combined variable emissivity that is based on the partial pressure of CO_2 and H_2O, flame luminosity and wall emissivity. In order to obtain an overall heat balance within the furnace, an emissivity correction factor (FQ1) is used. This correction factor is based, in part, upon the fact that a distribution of temperatures and gas compositions occurs in each zone of the furnace. Wall emissivity will also vary depending on slagging characteristics of the coal. The application of the emissivity correction factor is shown in the following equation:

3.1.1 Multiple Zone Furnace Model - Cont'd.

$$e_z = FQ1 \frac{1}{\frac{1}{eg} + \frac{1}{ew} - 1}$$

Where:

e_z = emissivity of any zone

eg = theoretical emissivity of the gas based on the concentration of CO_2 and H_2O.

ew = emissivity of the walls

FQ1 = emissivity correction factor

The emissivity of CO_2 and H_2O curves are a function of radiating length, which is a volume/area relationship.

Thus, this procedure has the capability of accounting for the effect of changes in geometry for different sizes and shapes of combustors.

3.1.2 Convection Pass Model

The convection pass performance program can calculate heat transfer performance, select critical superheater tube materials, economically group materials and calculate cold fluid superheater and reheater pressure drop for a coal, oil or natural gas designed boiler with series or divided flow gas paths, series or parallel flow steam paths, and single or double stage primary superheaters.

While the actual model and heat transfer calculations are complex, the mathematical explanation for evaluating surface effectiveness or cleanliness can best be described with the following basic heat transfer quotation for a tube bank:

$$Q = U \times A \times \Delta T \times K_f \text{ , Btu/Hr}$$

Where: Q = Heat absorbed by a tube bank (s), BTU/hr

U = Theoretical overall conductance between the gas and steam (water) for normally clean surfaces, Btu/ft.^{2} - hr - ^oF

A = Surface area of the tube bank, ft^2

3.1.2 Convection Pass Model - Cont'd.

ΔT = Log mean temperature difference between the gas and steam (water) entering and leaving the bank, ^{o}F

K_f = Surface effectiveness or cleanliness factor (variable)

The area is fixed. The parameters Q,U, and ΔT can be measured or calculated. The K_f factor is the correction between what the heat absorption should be with normally clean surfaces (U x A x ΔT) and what was actually measured (Q). Empirical data provides high prediction accuracy due to the fact that all of the measured variables are items routinely measured with a high degree of reliability without any need for special instrumentation.

3.2 Oil - Firing Performance

1. The B&W furnace performance model was used to establish thermal efficiency, flue gas weight, flue gas composition, furnace exit gas temperature, combustion air requirements and fuel requirements on oil-firing for all four units. This full load performance on oil was used as the maximum unit capability for subsequent calculations on unit deration.

3.2 Oil - Firing Performance - Cont'd.

2. The B&W convection pass model was then used to establish the following, for each unit:
   - bank heat absorptions
   - flue gas temperatures
   - steam (water) temperatures
   - tube metal temperatures
   - flue gas velocities
   - spray water requirements
   - gas recirculation requirements (if applicable)

3.3 Pulverized Coal-Firing Performance

1. Both the high and low ash coals were investigated and maximum boiler design parameters were determined per B&W Standards.

2. Using the B&W furnace model the discrete boiler deration, resulting from application of each maximum design parameter, was determined for all four boilers firing both high and low ash PC.

3. The B&W convection pass model was run for each of the maximum attainable loads on each unit.

3.3 Pulverized Coal-Firing Performance - Cont'd.

4. A qualitative assessment of each unit was performed to determine the equipment modifications necessary to fire pulverized coal.

5. A qualitative assessment of each unit was performed to indicate pressure part changes that could conceivably reduce the unit deration on PC firing.

3.4 CWF Firing Performance

1. Both the high and low ash CWF's were investigated and maximum boiler design parameters were determined based primarily on the performance indices of the parent coal.

2. Calculations were undertaken to determine the expected reduction if flame temperature between each PC fuel and CWF, due to the presence of additional moisture.

3. Using the B&W furnace model the discrete boiler deration, resulting from application of each maximum design parameter, was determined for all four boilers firing both high and low ash CWF.

3.4 CWF Firing Performance - Cont'd.

4. The B&W convection pass model was run for each of the maximum attainable loads on each unit.

5. Calculations were then performed to determine the necessary changes in auxiliary equipment (such as regenerative air preheaters, fans,etc.) in order to achieve the maximum attainable boiler load for each unit. These calculations were performed for both high and low ash fuels.

6. A qualitative assessment of each unit was performed to indicate pressure part changes that could conceivably reduce the unit deration on CWF firing.

4.0 DESCRIPTION OF STUDY UNITS SELECTED

4.1 General

Two very different boiler styles were used in this study; the El Paso design and the Carolina design. The El Paso design is characterized by a horizontal arrangement of all heating surfaces, which can be drained by gravity through drain connections. The Carolina design, on the other hand, has non-drainable heating surface platens located in the high flue gas temperature regions in the upper furnace and in the crossover section; while the surface located in the vertical down-pass section is normally all drainable horizontal surface. Four units were developed for anlaysis, a small and large unit of each boiler type. Care was taken in developing these units to avoid any site-specific design details and adhere to B&W's Standard Design guidelines for oil-firing.

A review of existing Canadian East Coast boilers was performed to ensure that existing oil-designed unit performance parameters are comparable to the study unit developed. This was done to augment the usefulness of this study.

4.2 El Paso Units

The small El Paso style unit developed is shown in Figure 4.1. The surface is arranged with secondary and primary superheat in the up-pass and economizer in the down-pass. The superheated steam exit temperature is controlled by a single-stage of attemperation. The unit is single-wall-fired with nine oil burners arranged in three levels of three burners wide.

A physical summary of this unit is given in Table 4.1.

The large El Paso design is shown in Figure 4.2. The heating surface is arranged with reheat and secondary superheat surface in the up-pass and primary superheat and economizer in the down-pass. The superheat steam exit temperature is controlled by attemperation. Burner level modulation is used to maintain reheat steam exit temperature at reduced boiler loads. This unit is single-wall fired with twelve oil-burners arranged in four levels of three burners wide. A physical summary of this unit is given in Table 4.2.

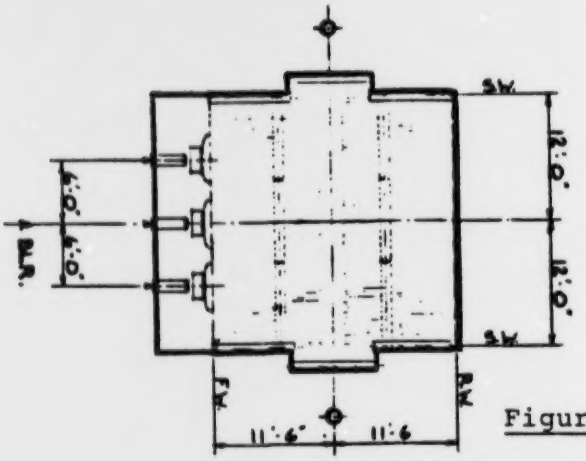
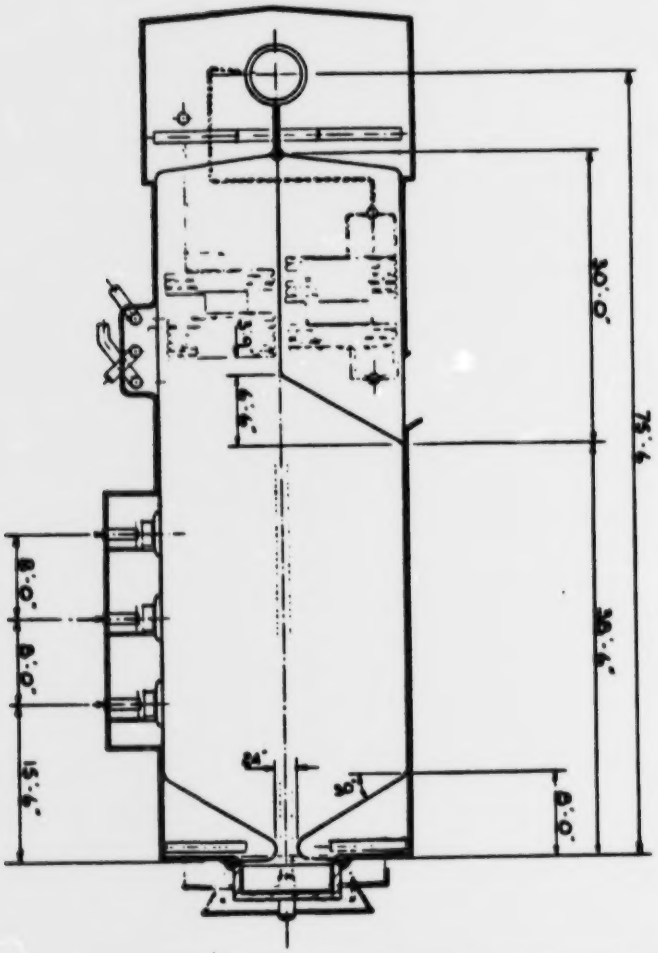


Figure 4.1 Small El Paso Design



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EQUIPMENT 700 MLB/HR RADIANT EL PASO BOILER

CUSTOMER D.S.S.C. COAL/WATER FUEL DERATING STUDY

DRAWN E.N.V. DATE 84 FILE No. 14 80 25440-1-9134 REV.

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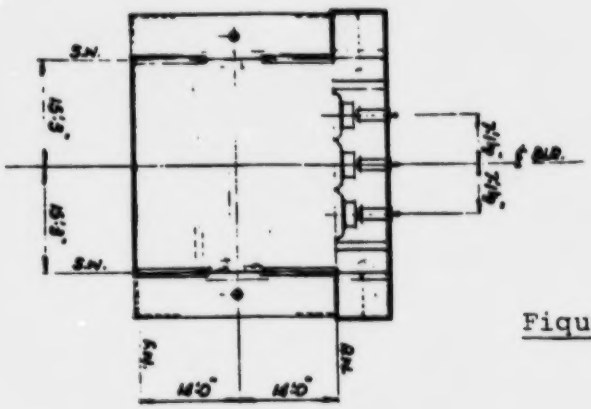
Table 4.1 Physical Summary of Small El Paso Design

Furnace Width	24 ft.
Furnace Depth	23 ft.
Furnace Height	
- Centre-line of lower wall header to drum centre	75.5 ft.
Burner Clearances	
- horizontal	5.5 ft.
- vertical	8 ft.
- proximity to water-cooled surface	6.5 ft.
No. of burners	9
Hopper slope	30°
Hopper throat	2 ft.
Convection surface side spacing (on centres)	
- secondary superheat	9 inches
- primary superheat	6 inches
- economizer	3 inches



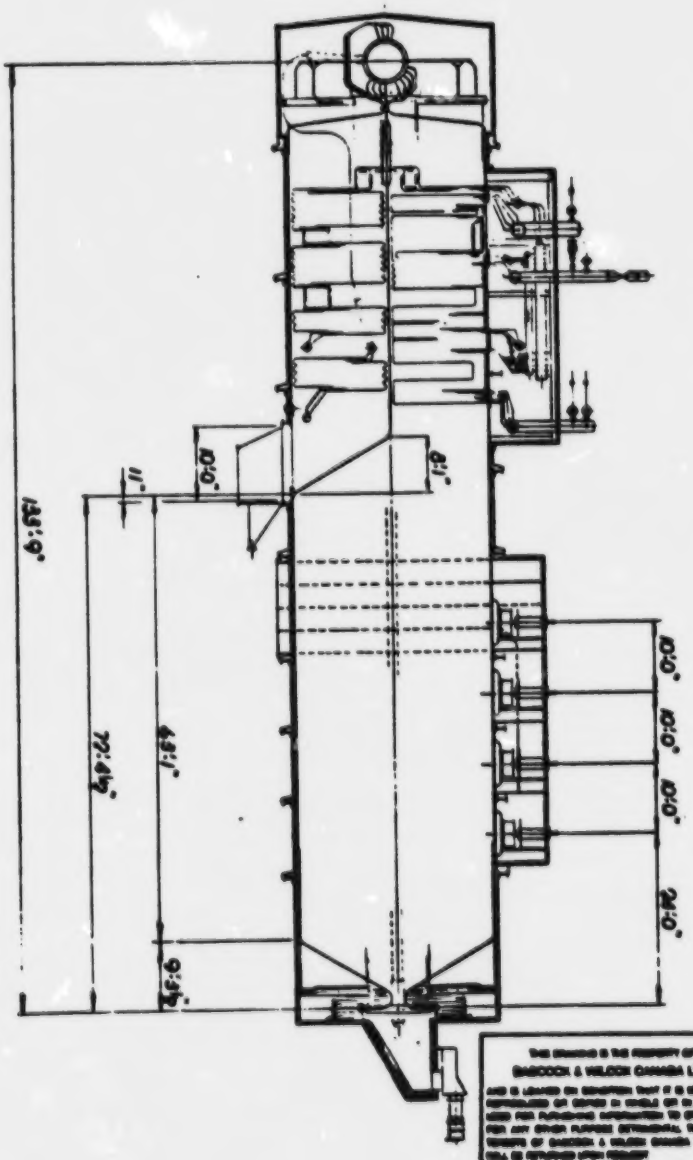


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Figure 4.2 Large El Paso Design

Table 4.2: Physical Summary of Large El Paso Design

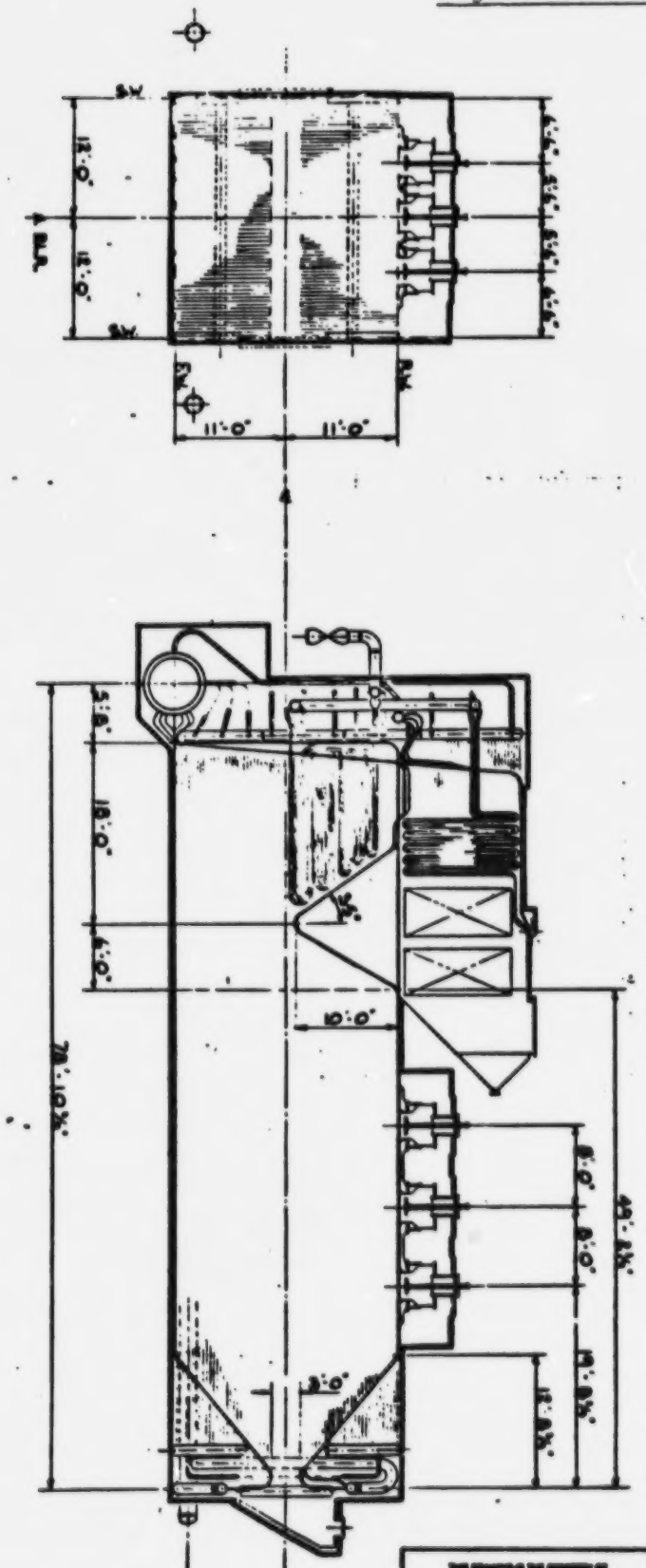
Furnace width	30 ft. 6 inches
Furnace depth	28 ft.
Furnace height	
- centre-line of lower wall header to drum centre	133 ft. 9 inches
Burner clearances	
- horizontal	7 ft. 2 inches
- vertical	10 ft.
- proximity to water-cooled surface	8 ft. 2 inches
No. of burners	12
Hopper slope	30^{o}
Hopper throat	2 ft.
Convection surface side spacing (on centres)	
- reheat	18 and 6 inches
- secondary superheat	18 and 6 inches
- primary superheat	6 and 4 inches
- economizer	4 inches

4.3 Carolina Units

The small Carolina style unit developed is shown in Figure 4.3. The surface is arranged with pendant superheat surface in the upper furnace and crossover section and horizontal primary superheat and economizer in the downpass. The superheated steam exit temperature is controlled by a single-stage of attemperation. The unit is single wall fired with nine oil burners arranged in three levels of three burners wide. A physical summary of this unit is given in Table 4.3.

The large Carolina design is shown in Figure 4.4. The heating surface is arranged with pendant secondary superheat and reheat in the upper furnace and cross-over section and horizontal primary superheat and economizer in the downpass. The superheat steam exit temperature is controlled by attemperation. Gas recirculation is used to maintain reheat steam exit temperature at reduced loads. This unit is single wall-fired with twelve oil burners arranged in three levels of four burners wide. A physical summary of this unit is given in Table 4.4.

Figure 4.3: Small Carolina Design



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EQUIPMENT 700 MLB/HR RADIANT CAROLINA BOILER

CUSTOMER D.S.S.C. COAL/WATER FUEL : DERATING STUDY

DRAWN EnV DATE 88 PROJ. No. 1980 23440-1-9130 REV.

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Table 4.3: Physical Summary of Small Carolina Design

Furnace width	24 ft.
Furnace depth	22 ft.
Furnace height	
- Centre-line of lower wall header to drum centre	78 ft. 10 inches
Burner clearances	
- horizontal	5 ft. 6 inches
- vertical	8 ft.
- proximity to water-cooled surface	6 ft. 6 inches
No. of burners	9
Hopper slope	50°
Hopper throat	3 ft.
Convection surface side spacing (On centres)	
- Secondary superheat	18 and 9 inches
- primary superheat	4 inches
- economizer	2 ½ inches

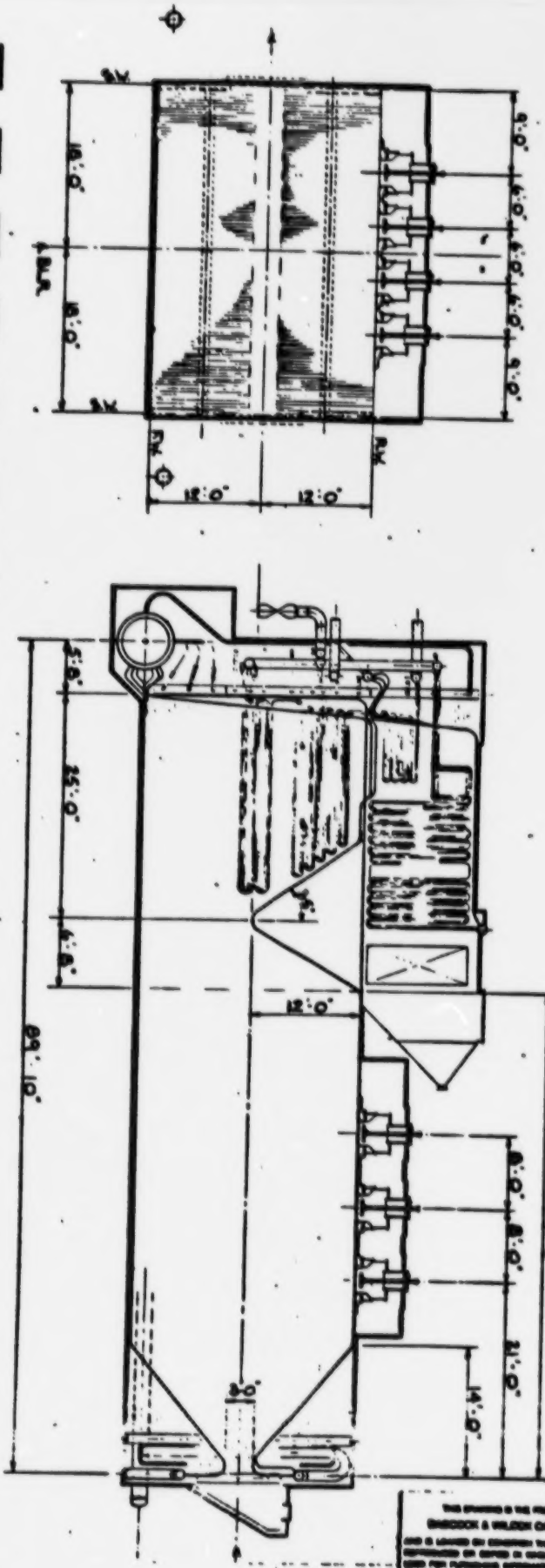

Figure 4.4: Large Carolina Design

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125 mW/HR RADIANT CAROLINA BOILER

D306 COAL/WATER FUEL - DERATING STUDY

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Table 4.4: Physical Summary of Large Carolina Design

Furnace width	36 ft.
Furnace depth	24 ft.
Furnace height	
- Centre-line of lower wall header to drum centre	89 ft. 10 inches
Burner Clearances	
- horizontal	6 ft.
- vertical	8 ft.
- proximity to water-cooled surface	9 ft
No. of burners	12
Hopper slope	50°
Hopper throat	3 ft.
Convection surface side spacing (on centres)	
- secondary superheat	18 and 9 inches
- reheat	4 ½ inches
- primary superheat	4 inches
- economizer	2 ½ inches

5.0 FUELS

The fuel analysis used for heavy oil, parent pulverized coal and resulting coal/water slurries are given in Table 5.1, 5.2 and 5.3 respectively. Based on consultation with Canmet and Carbogel it was agreed that;

i) no change will occur in the slagging/fouling potential of the CWF compared with the parent pulverized coal.

ii) no change will occur in the ultimate analysis of the coal ash as a result of beneficiation

iii) no change will occur in ash fusion temperature of the CWF compared with the parent pulverized coal.

The pulverized coal and its resulting coal/water slurry were classified as having high/severe slagging and medium fouling tendencies, according to B&W index definitions.

Slagging is defined as ash deposition on furnace surface or convection surface exposed to radiant heat or where ash deposits remain molten.

5.0 FUELS - Cont'd.

Fouling is defined as ash deposition on convection surface not exposed to radiant heat and may be formed by impaction or chemcial bonding or both.

Table 5.1: Heavy Fuel Oil Details

Ultimate Analysis (as fired)

Carbon	87.87%
Hydrogen	10.33%
Sulphur	1.16%
Oxygen	0.50%
Nitrogen	0.14%
	100 %

Heating Value

HHV = 18400 BTU/lb

Table 5.2: Pulverized Coal Details

	High Ash	Low Ash
Ultimate Analysis (as fired % by wt)		
Carbon	66.20	70.30
Hydrogen	4.42	4.69
Sulphur	3.31	3.51
Nitrogen	1.26	1.34
Oxygen	6.74	7.16
Ash	8.07	3.00
Moisture	10.00	10.00
	100	100
Heating Value		
HHV	12000 BTU/lb.	12800 BTU/lb.
Ash Analysis (dry - % by wt)		
SiO_2	32.54	32.54
Fe_2O_3	39.42	39.42
P_2O_3	0.08	0.08
MgO	0.82	0.82
Na_2O	0.59	0.59
Al_2O_3	20.44	20.44
TiO_2	0.80	0.80
CaO	1.64	1.64
SO_3	0.95	0.95
K_2O	1.14	1.14
Ash Fusibility		
Initial Deformation	2490 F(Oxid) 2000 F(red)	2490 F(Oxid) 2000 F(red)

Table 5.3: Coal/Water Slurry Details

	High Ash	Low Ash
Ultimate Analysis (as-fired % by wt)		
Carbon	51.49	54.86
Hydrogen	3.44	3.66
Sulphur	2.58	2.74
Nitrogen	0.98	1.04
Oxygen	5.23	5.60
Ash	6.28	2.10
Moisture	30.00	30.00
	100	100
Heating Value		
HHV	9323 BTU/lb.	9928 BTU/lb.
Ash Analysis (dry % by wt.)		
SiO_2	32.54	32.54
Fe_2O_3	39.42	39.42
P_2O_3	0.08	0.08
MgO	0.82	0.82
Na_2O	0.59	0.59
Al_2O_3	20.44	20.44
TiO_2	0.80	0.80
CaO	1.64	1.64
SO_3	0.95	0.95
K_2O	1.14	1.14
Ash Fusibility		
Initial Deformation	2490 F(oxid)	2490 F(Oxid)
	2000 F(red)	2000 F(red)

6.0 IMPORTANT BOILER PERFORMANCE PARAMETERS

In determining the expected derations to fire various fuels in the oil-designed units, a number of Key boiler performance parameters must be revised. Figure 6.1 illustrates the method of calculating some of these parameters.

Maximum Heat Input/Burner

This limit is based upon burner proximity to water-cooled surface, adjacent burner spacing and furnace depth. Care must be taken to avoid excessively high spot absorption rates, excessive slagging and flame impingement. For unit derations on CWF firing the limitations for the parent PC were used.

Burner Zone Release Rate & Plan Area Release Rate

The purpose of this limit is to minimuze lower furnace slagging and to avoid excessive fly-ash carryover from the furnace. This limitation is directly related to the slagging classification and expected reactivity of the coal. For this study the limit for the parent PC was used for CWF firing deration calculations.

6.0

Furnace Liberation Rate and Furnace Exit Gas Temperature

These two limits are related and the overall size of the furnace limits the maximum allowable load:

i) for acceptable FEGT to the convection pass consistent with the ash characteristics.

ii) to ensure sufficient volume is available for complete combustion in the furnace.

Ideally, the furnace box must be large enough to permit the furnace gas and ash particles to cool below the Initital Deformation Temperature of the ash. Volatile coal ash constituents, if allowed to condense on fly ash particles and deposit on boiler tubes in areas where the temperatures are in a range where constituents remain liquid, will react chemically with the fly ash, other deposits and the flue gas to form bonded deposits. This fouling phenomena limits the allowable furnace exit gas temperature and is very dependent on the coal ash analysis characteristics.

6.0

Furnace Liberation Rate and Furnace Exit Gas Temperature - Cont'd.

It is known that some coal/water slurries exhibit a reduction in the IDT and a corresponding increase in the sodium content of the fuel ash versus the parent coal [4]. Some slurry manufacturers claim no adverse effects on ash properties result from their process. Carbogel advise that their slurry "contains extremely little, if any, of the elements which might affect ash properties or influence the fouling potential of the fuel"[5]. As previously mentioned no changes in ash properties are accounted for in this study. Many slurry manufacturers are switching from sodium based additives to ammonia base to eliminate any possible effects on CWS slagging/ fouling potential. For this study the limits used for furnace exit temperature and furnace liberation are the same on CWF as parent PC.

Convection Pass Maximum Gas Velocity

Metal loss due to erosion is proportional to the total ash quantity passing through the boiler and an exponential function of flue gas velocity. Since the total ash is fixed, for a given fuel, limiting flue gas velocities to acceptable levels is the method used to ensure minimal erosion.

6.0

Convection Pass Maximum Gas Velocity - Cont'd.

Flue gas velocities in the neighbourhood of 100-125 ft. per second are permitted on oil firing without the need for erosion barriers. For pulverized coal fuel with a relatively high ash content and indicated high erosion potential (high silica or alumina content) the flue gas velocity is allowed to reach 50 ft. per second before erosion barriers are necessary; maximum allowable velocity on coal is 65 ft. per second with erosion barriers. Erosion barriers are placed at the ends of horizontal tube banks to protect the tube bends from the erosive effects of local high gas velocities caused by gas laning. These erosion barriers reduce the overall available gas free flow area and result in higher average gas velocities for a given flue gas mass flow. For pulverized-coal fuel with a relatively low ash content and a high erosion potential, the flue gas velocity limit may be at 65 ft. per second without the need for erosion barriers.

In CWF firing the total ash produced will be approximately the same as for PC firing but the ash concentration in the flue gas will be somewhat reduced because of the increase in flue gas weight. Pulverized coal velocity limits were used for determining the necessary unit derations for high ash and low ash CWF firing in this study.

6.0

Tube Side Spacing vs. Flue Gas Temperature

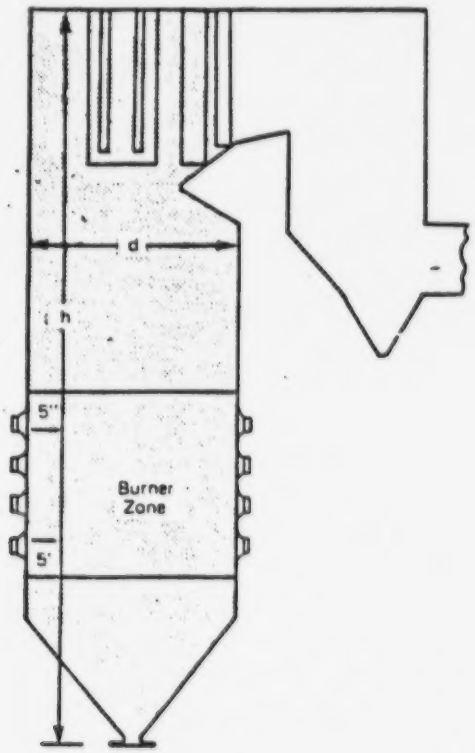
The transverse tube spacing for convective heating surface is maintained wide enough to reduce the fouling rate and prevent bridging of ash deposits between adjacent tube bundles.

This also provides sufficient gas free flow area to ensure acceptable flue gas velocities, thereby reducing erosion potential during coal-firing. The lower limit on transverse tube spacing is based on the need to permit effective penetration of the sootblowing jet. The design limits for pulverized coal were employed when considering CWF firing.

Figure 6.1 Furnace Performance Parameters

Furnace definitions.

Typical B&W
Radiant Boiler



Plan Area Release Rate ..... $\left[\frac{\text{input in fuel - BTU/HR}}{\text{w·d - FT}^2}\right]$ ..... BTU/FT² HR

Burner Zone Release Rate .... $\left[\frac{\text{heat release* - BTU/HR}}{\text{effective burner zone area - FT}^2}\right]$ ..... BTU/FT² HR

Furnace Release Rate ..... $\left[\frac{\text{heat release* - BTU/HR}}{\text{furn. flat projected area - FT}^2}\right]$ ..... BTU/FT³ HR

Furnace Liberation ..... $\left[\frac{\text{input in fuel - BTU/HR}}{\text{w·d·h - FT}^3}\right]$ ..... BTU/FT³ HR

* heat released and available from fuel and heated air.

7.0 BOILER LOAD DERATION TO FIRE COAL AND COAL/WATER SLURRY

7.1 General

The two small units do not have reheaters and their derations are therefore not affected by reheat steam temperature control methods. The large reheat units use steam temperature control methods; flue gas recirculation for the Carolina unit and burner input modulation for the El paso unit. Both of these control techniques biases heat absorption away from the furnace towards the convection sections of the boiler. There is also an effect on the furnace exit gas temperature as a result of these reheat control methods and this effect will influence the deration of the units.

Firing coal/water slurry of 30 percent moisture will result in increased flue gas mass flow which will adversely affect erosion potential and increase heat absorption to the convection sections of the boiler.

Calculations reveal that adiabatic flame temperature during coal/water slurry combustion will be in the neighbourhood of 220^{o}F lower than that of the parent pulverized coal.

7.1 General - Cont'd.

This is caused by the latent heat of vaporization necessary to overcome the additonal moisture in the slurry fuel and results in a lower fuel efficiency. This results in more fuel, air, flue gas and a higher heat input rate for the same boiler output rate. Beneficiation of the coal will result in an improvement in fuel efficiency and an improvement in attainable loads on low ash PC and CWF firing. The amount of improvement is a function of the type of beneficiation process used and the corresponding change in slagging/fouling potential effected. Erosion barriers were incorporated on the downpass rear wall at the top of the horizontal banks where the gas velocity exceeded 50 fps during high ash coal or CWF firing. This results in additional unit deration due to flue gas velocity limitations. An investigation into the acceptability of the oil-designed tube metal selection for all units revealed that no metal upgrades would be necessary for any of the maximum attainable loads on CWF firing.

7.2 Small El Paso Design

Figures 7.1 to 7.4 illustrate the maximum attainable boiler load for PC and CWF firing for the oil-designed small El Paso unit. Each design parameter was considered independently and its affect on boiler capacity determined.

When designing a furnace, the Engineer has available various burner arrangements from which to select. Once the number and size of burners is chosen, the furnace plan area dimensions are fixed by heat input and burner clearance limits. On small boilers with such relatively low heat inputs, the physical spacing necessary to install the burners results in conservative heat release rates in the burner zone. This results in no load derating effect from heat input/burner, burner zone release rate, or plan area release rate performance parameters for coal or CWF firing.

The furnace heat liberation rate (BTU/CU.FT.HR.) limit results in a maximum boiler load of 63% for pulverized coal-firing and 61% for coal/water slurry-firing. The furnace volume is normally determined by allowable furnace exit gas temperature on oil-firing.

7.2 Small El Paso Design - Cont'd.

The resulting furnace, due to the differences in HHV, gas emissivities, flame temperature, furnace wall cleanliness and allowable furnace exit gas temperatures, is undersized for PC of CWF combustion. The slightly lower attainable load for coal/water slurry-firing is a result of the reduced boiler efficiency due to the need to evaporate the additional moisture added during slurrying.

The allowable gas velocity through the convective heating surface results in a different maximum attainable load for each fuel; as follows:

Fuel	Flue Gas Velocity Limited Max. Attainable Boiler Load
High ash PC	57%
Low ash PC	65%
High ash CWF	55%
Low ash CWF	64%

The reduced unit deration for the beneficiated fuel is primarily due to the elimination of erosion barriers as a result of the decrease in erosion potential of the ash.

7.2 Small El Paso Design - Cont'd.

This permits the full use of the convection pass free flow area and hence, results in lower flue gas velocities. Once again, the reduced efficiency of CWF firing results in slightly greater gas flow for a given heat input and consequently slightly more unit deration than the PC fuel.

The allowable flue gas temperature vs. tube side spacing results in the same unit deration as the allowable furnace exit gas temperature limit for this particular unit size and style. This is due to the relatively tight sidespacing of the convective heating surface at the furnace exit. the maximum allowable boiler load is limited to 42% on PC firing and 41% on CWF firing.

FIGURE 7.1 SMALL EL PASO MAX. ATTAINABLE BOILER LOAD VS. PERFORMANCE LIMITS FOR HIGH ASH P.C.

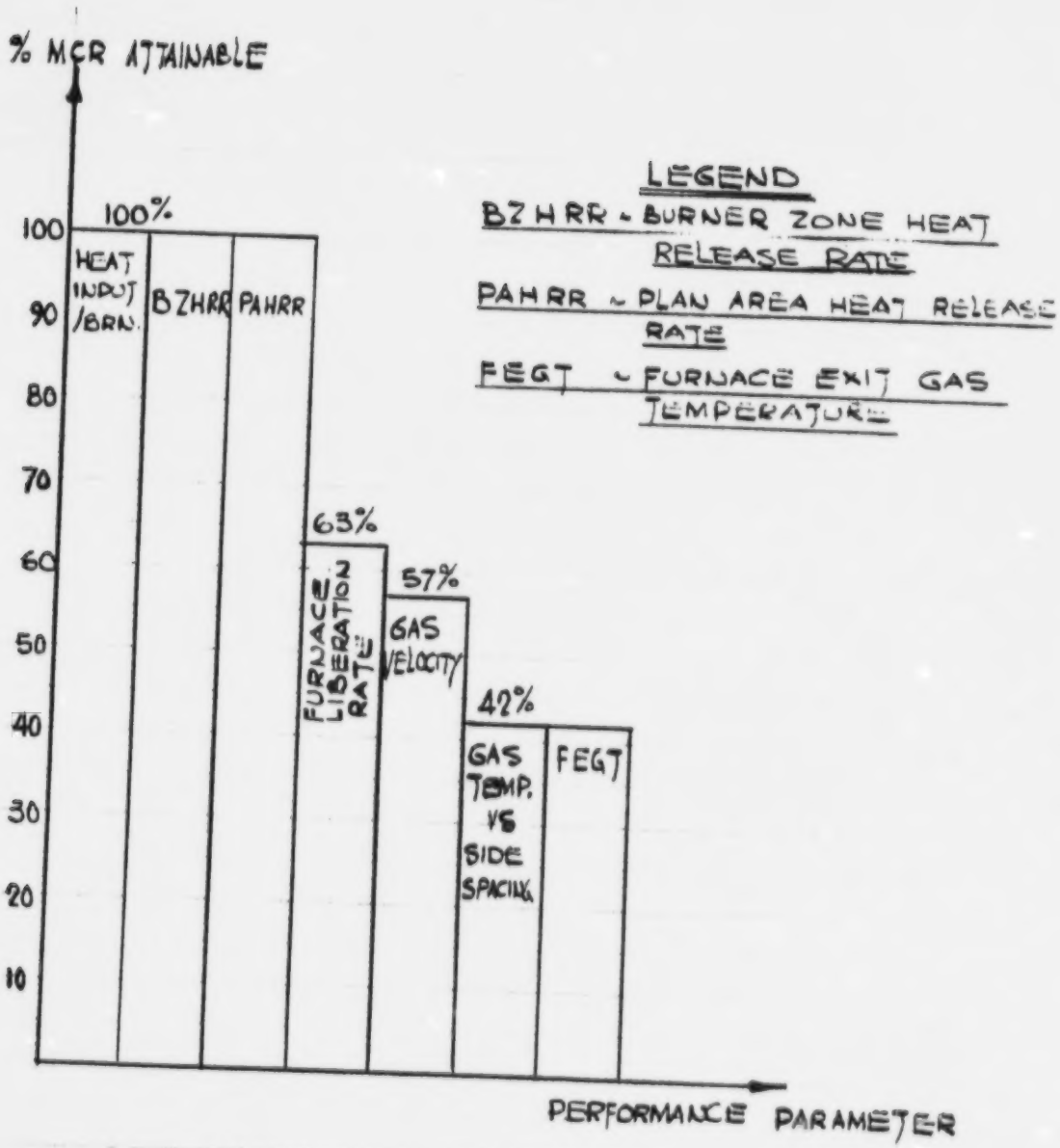


FIGURE 7.2 SMALL EL PASO
MAX. ATTAINABLE BOILER LOAD
VS PERFORMANCE LIMITS
FOR LOW ASH P.C.

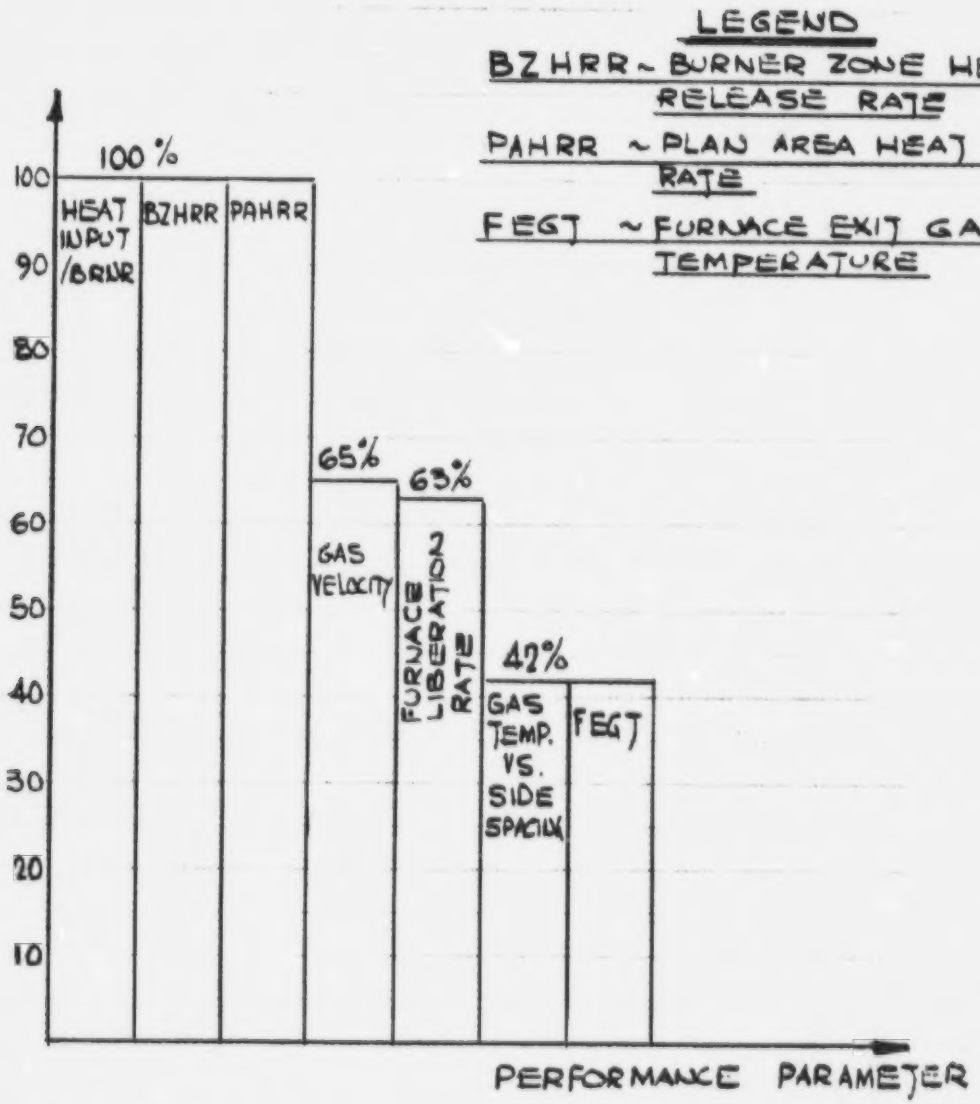


FIGURE 7.3 SMALL EL PASO

MAX. ATTAINABLE BOILER LOAD VS. PERFORMANCE LIMITS FOR HIGH ASH CWF

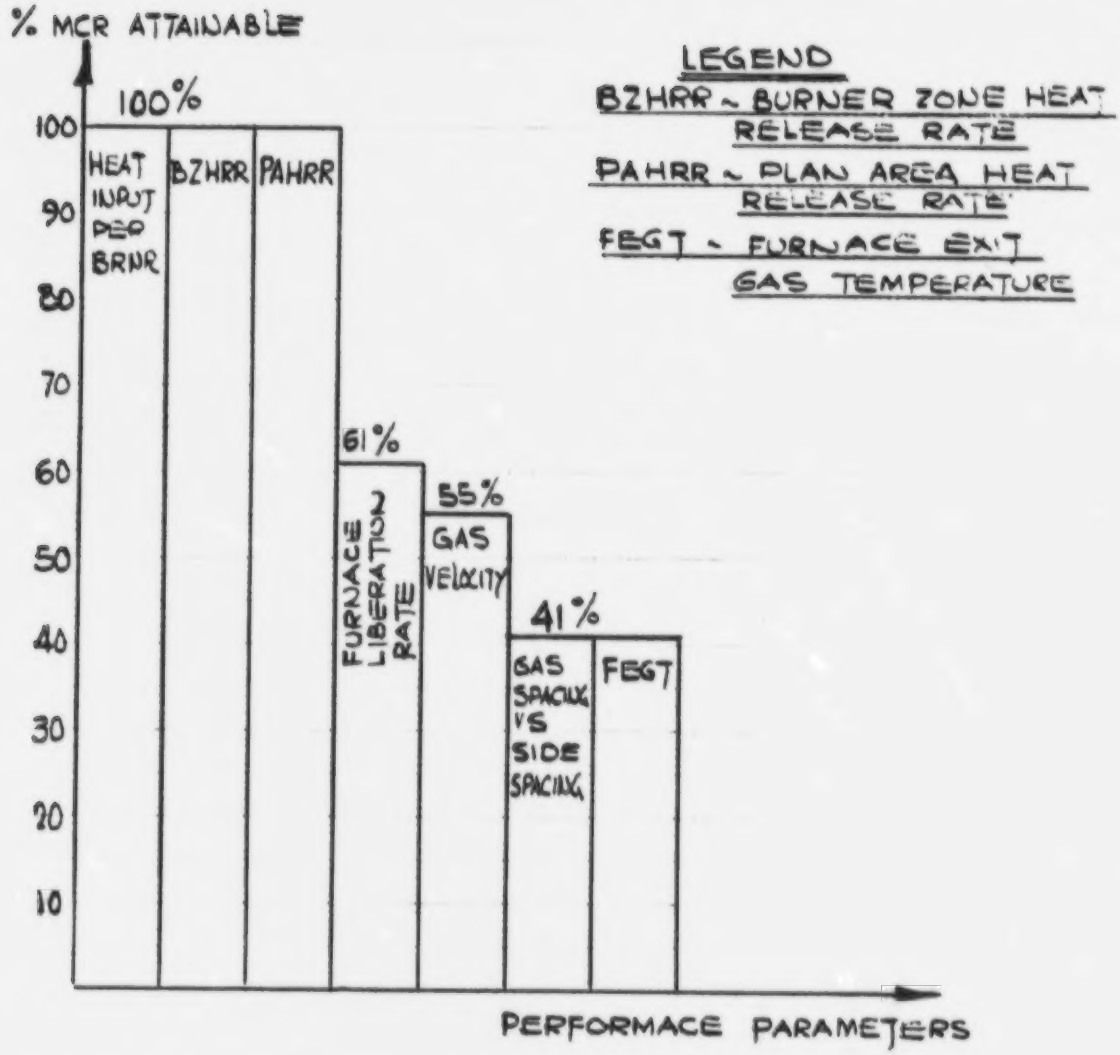
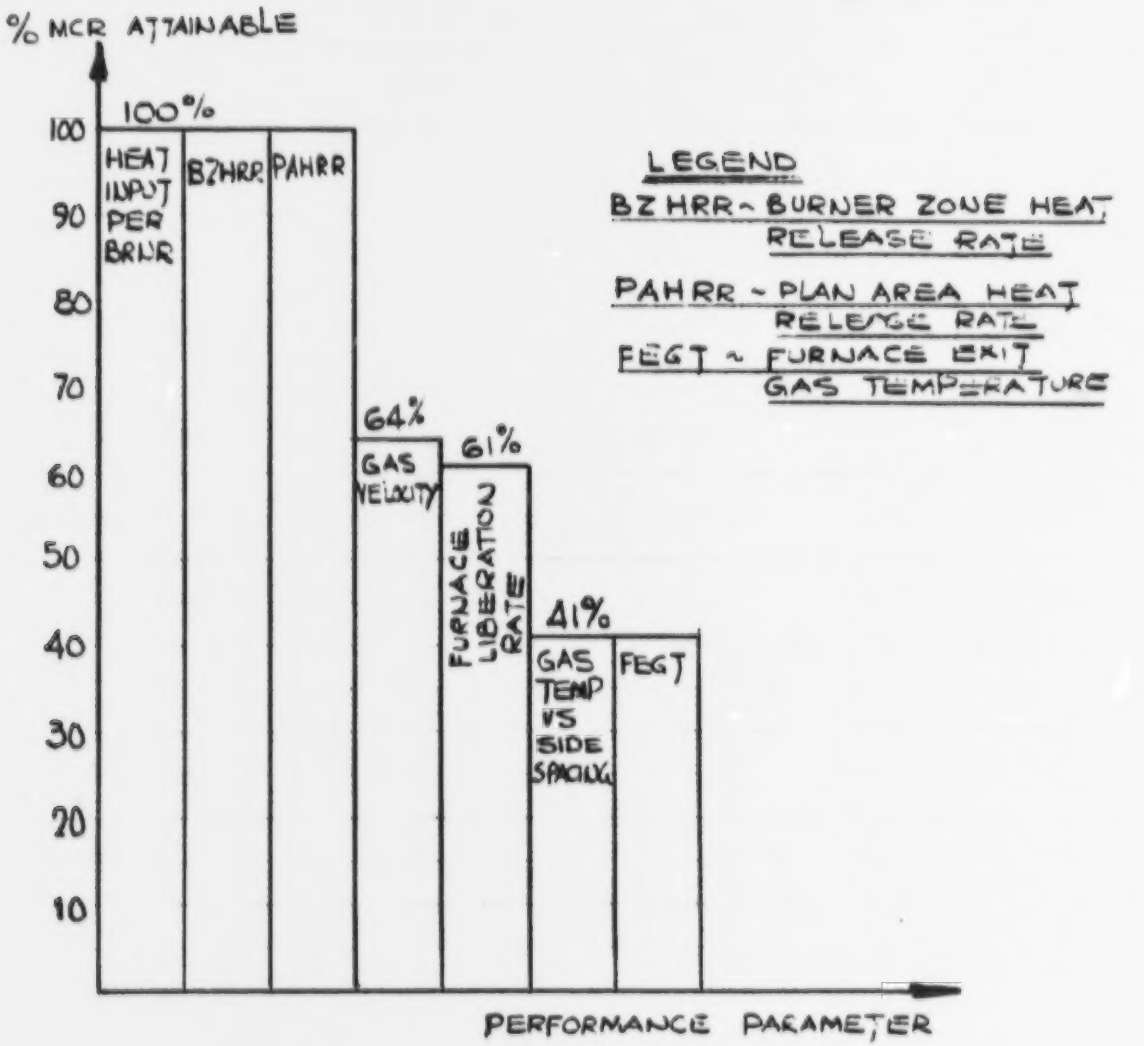


FIGURE 7.4 SMALL EL PASO
MAX. ATTAINABLE BOILER LOAD
VS PERFORMANCE LIMITS
FOR LOW ASH CWF



7.3 Large El Paso Design

Figures 7.5 to 7.8 illustrate the maximum attainable boiler load for PC and CWF firing for the oil-fired large El Paso unit.

The standard El Paso burner spacing for oil firing was adequate for PC and CWF firing, consequently no unit deration would be necessary to satisfy burner zone heat release rate limits. However, due to the increased slagging potential of PC and CWF plan area heat realease rate, furnace liberation rate and heat input per burner will result in some limitation on maximum attainable boiler load. As before, the additional moisture contained in CWF results in reduced fuel efficiency and slightly lower attainable loads.

7.3 Large El Paso Design - Cont'd.

Max. Attainable Boiler Load

Fuel	PAHRR	Furn. Liber'n.	Heat Input/Bnr.
High Ash PC	97%	83%	90%
Low Ash PC	97%	83%	90%
High Ash CWF	94%	80%	87%
Low Ash CWF	94%	80%	87%

The tube side spacing of the first reheater bank limits the maximum attainable boiler load due to fouling limitations. This results in the same unit deration for the furnace exit gas temperature limit and gas temperature vs. tube side spacing limitation.

Satisfying these two performance limits results in a maximum attainable boiler load of 63% for PC firing and 62% for CWF firing.

7.3 Large El Paso Design - Cont'd.

The flue gas velocity entering the first primary superheater bank in the downpass severely limits the attainable boiler load during firing of high ash PC and CWF. This is a result of the need for erosion barriers on the rear wall to combat the expected tube erosion during high ash fuel firing. The following loads are attainable on gas velocity limitations:

Fuel		Flue Gas Velocity Limited Max.Attainable Boiler Load
High Ash	PC	57%
Low Ash	PC	63%
High Ash	CWF	53%
Low Ash	CWF	61%

FIGURE 7-5 LARGE EL PASO
MAX. ATTAINABLE BOILER LOAD
VS PERFORMANCE LIMITS
FOR HIGH ASH P.C

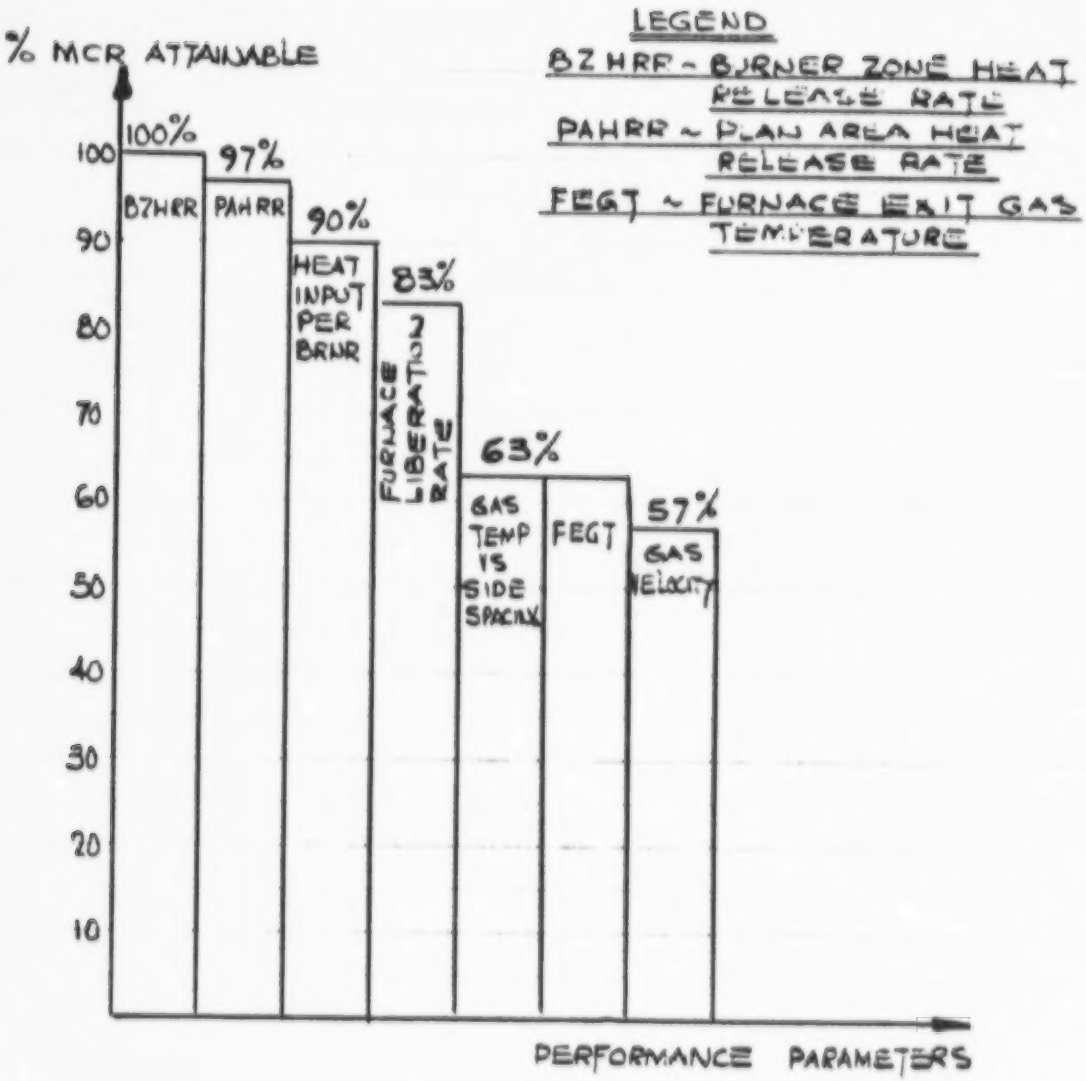


FIGURE 7.6 LARGE EL PASO
MAX. ATTAINABLE BOILER LOAD
VS PERFORMANCE LIMITS
FOR LOW ASH P.C

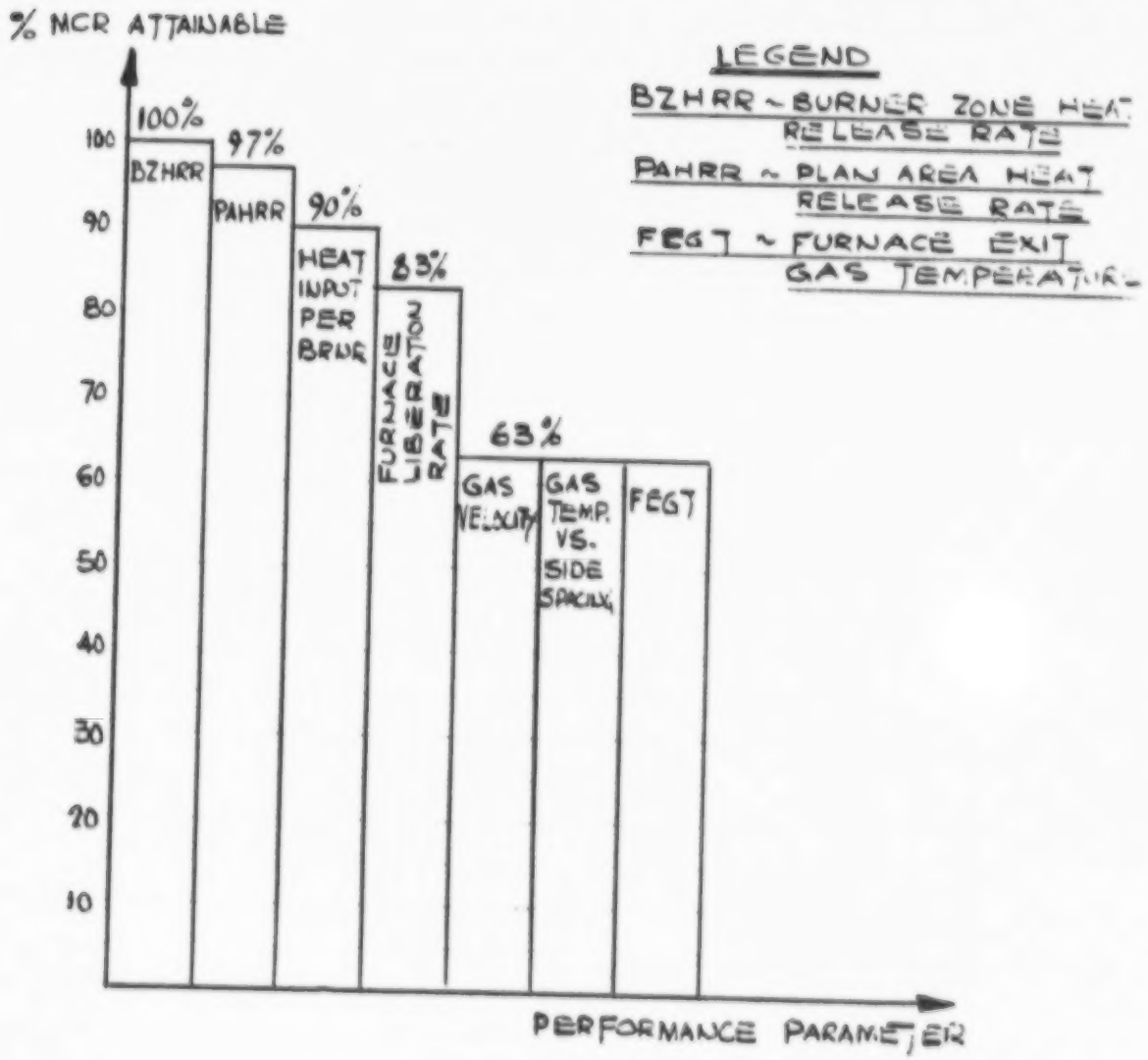


FIGURE 7.7 LARGE EL PASO
MAX. ATTAINABLE LOAD VS
PERFORMANCE LIMITS
FOR HASH CWF

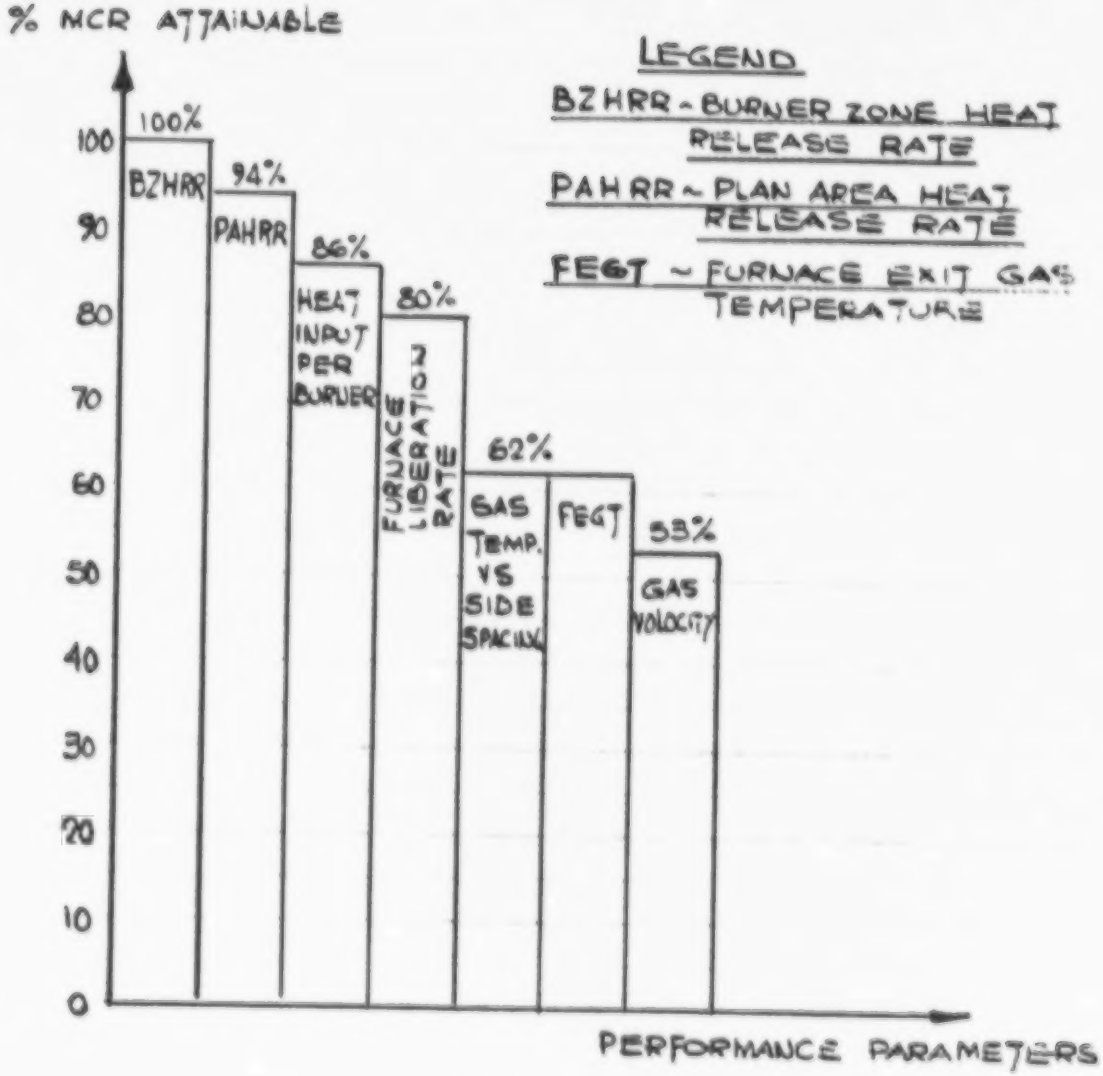
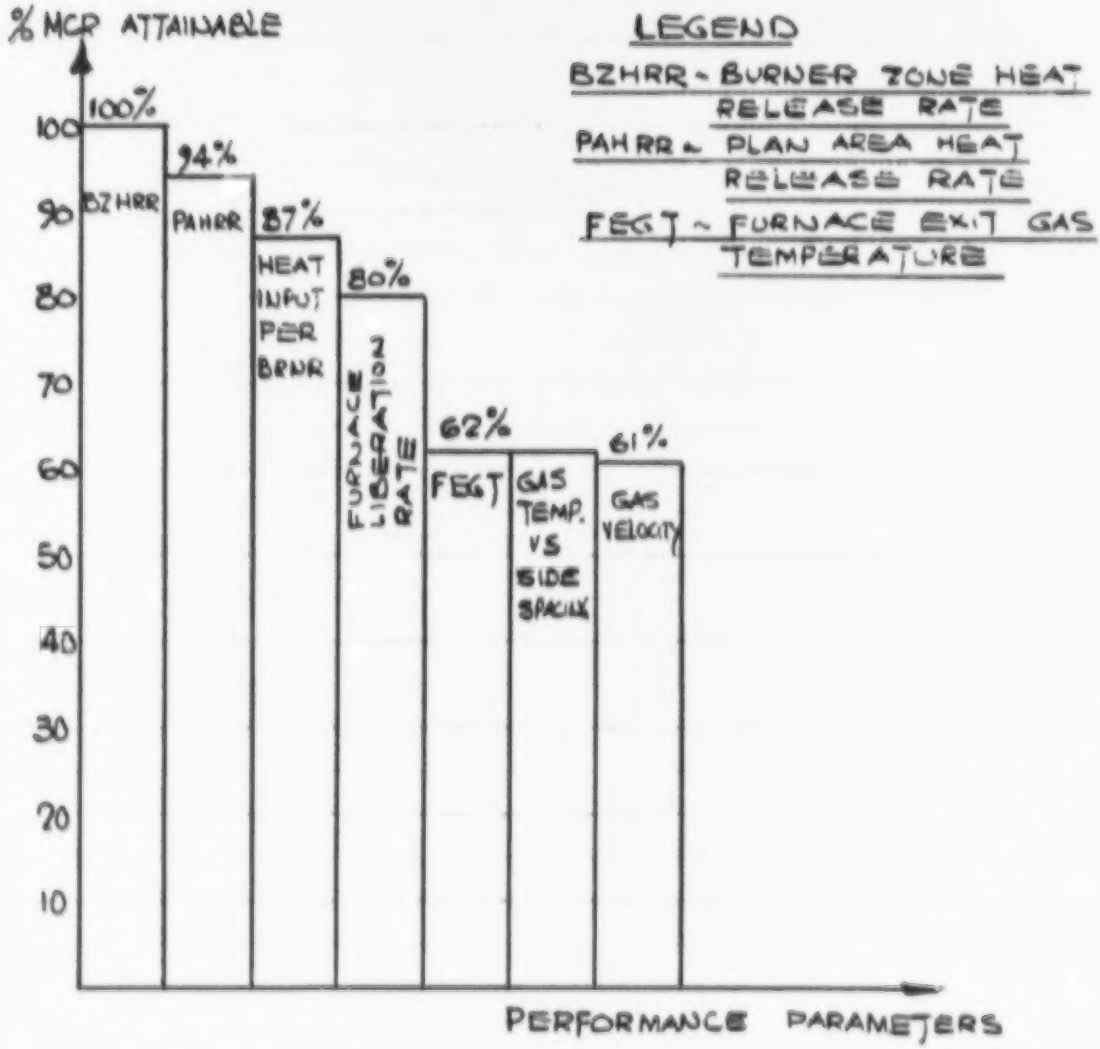


FIGURE 7.8 LARGE EL PASO
MAX ATTAINABLE LOAD VS.
PERFORMANCE LIMITS
FOR LASH CWF



7.2 Small Carolina Design

Figures 7.9 to 7.12 illustrate the maximum attainable boiler load for PC and CWF firing for the oil designed small Carolina -Style unit.

Similar to the situation in the small El Paso design, the physical spacing required for the installation of burners results in a conservative heat release rate at such relatively low boiler heat inputs. As before this results in no unit deration due to heat input/burner, burner zone heat release rate or plan area heat release rate for PC or CWF firing.

The Carolina-Style design standards results in a relatively liberal furnace volume and consequently the unit deration to fire PC and CWF is minimal due to furnace volumetric heat liberation rate limits. The maximum attainable boiler load, based on furnace liberation, is 84% for PC firing and 81% for CWF firing.

As before, a higher unit deration,due to allowable flue gas velocities,is obtained when firing the high ash fuels. This is again due to the requirement for erosion barriers to offset the erosion potential of high ash fuel.

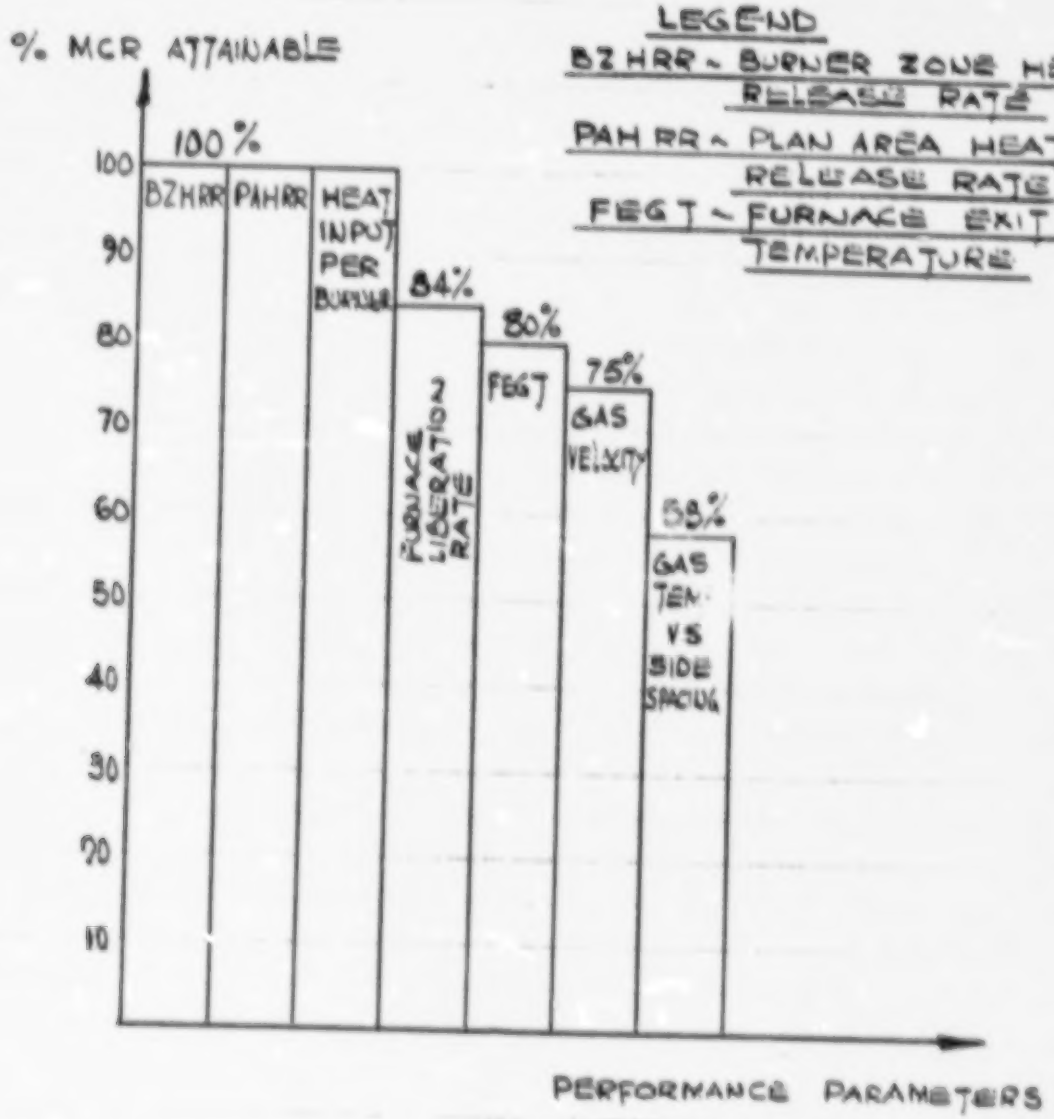
7.4 Small Carolina Design - Cont'd.

The following maximum attainable loads were calculated:

Fuel		Fuel Gas Velocity Limited Max. Attainable Boiler Load
High Ash	PC	75%
Low Ash	PC	87%
High Ash	CWF	71%
Low Ash	CWF	83%

The flue gas temperature entering the horizontal primary superheater bank limits the maximum attainable load to 58% on PC firing and 60% on CWF firing.

FIGURE 7.9 SMALL CAROLINA MAX. ATTAINABLE LOAD VS PERFORMANCE LIMIT FOR HASH R.C. FIRING



LEGEND

BZ HRR ~ BURNER ZONE HEAT RELEASE RATE

PAH RR ~ PLAN AREA HEAT RELEASE RATE

FEGT ~ FURNACE EXIT GAS TEMPERATURE

FIGURE 7.10 SMALL CAROLINA
MAX. ATTAINABLE LOAD
VS PERFORMANCE LIMIT
FOR LASH P.C. FIRING

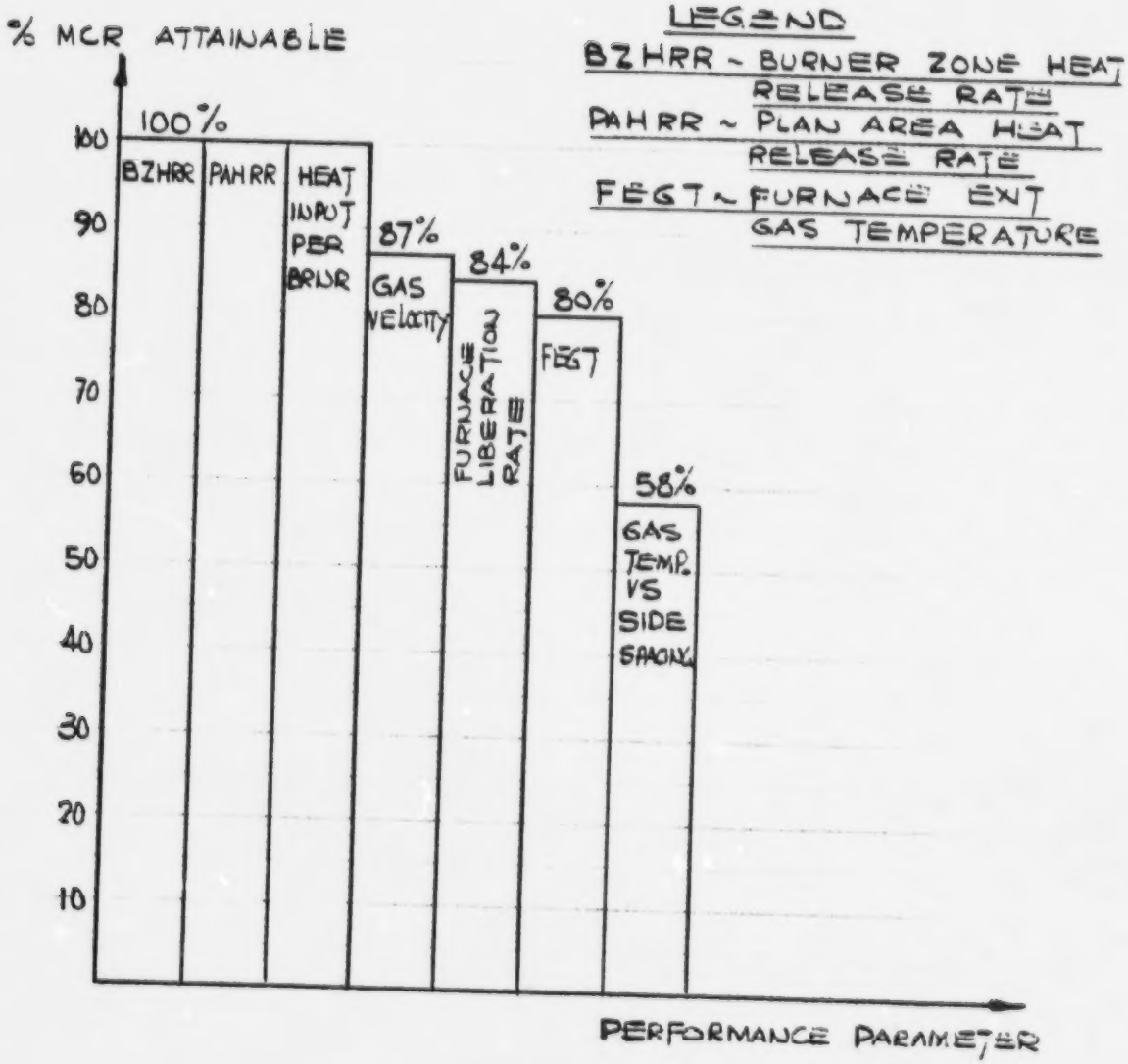


FIGURE 7.11 SMALL CAROLINA MAX. ATTAINABLE LOAD VS PERFORMANCE LIMITS FOR HASH CWF FIRING.

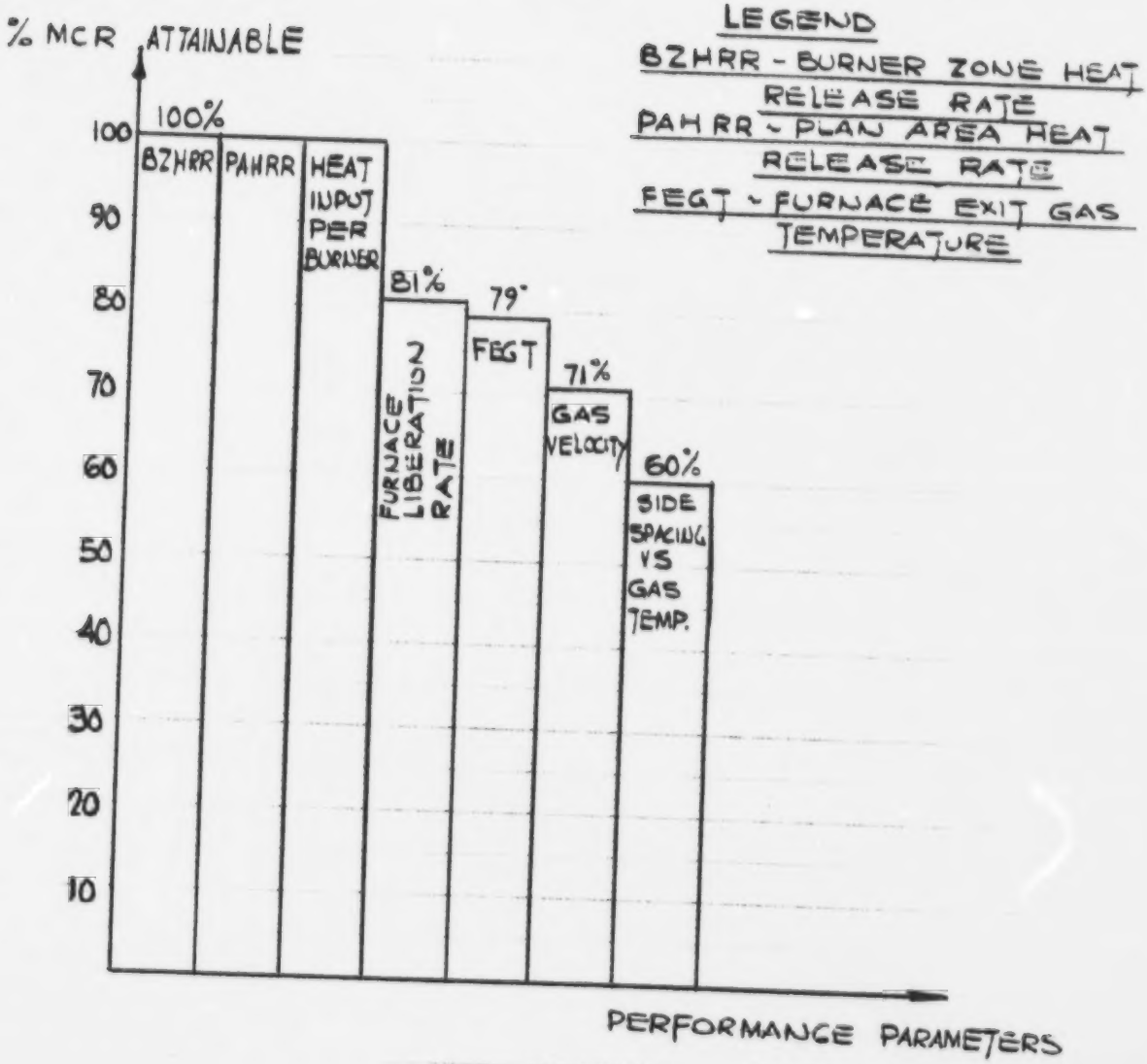
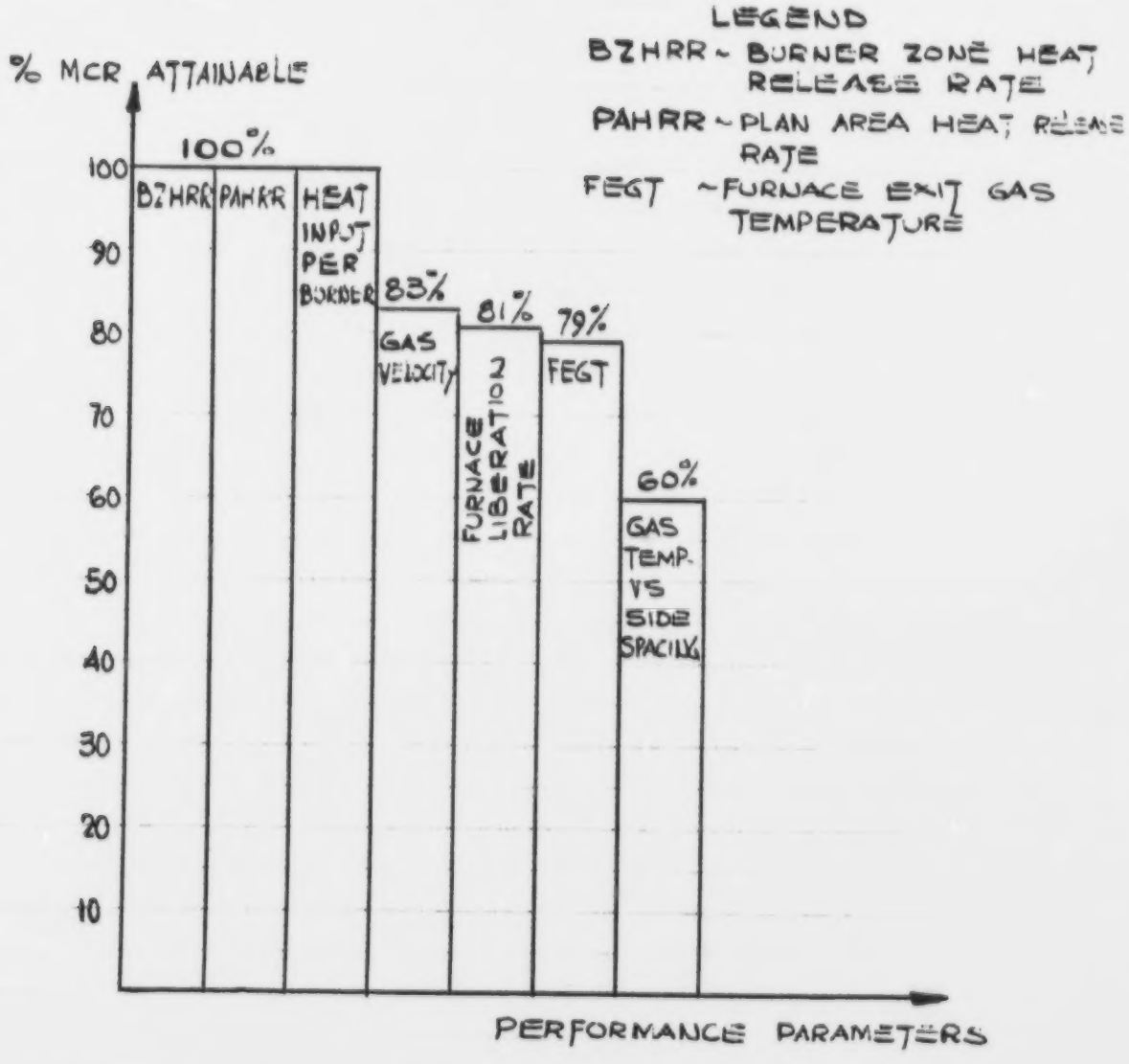


FIGURE 7.12 SMALL CAROLINA
MAX. ATTAINABLE LOAD VS
PERFORMANCE LIMITS
FOR LASH CWF FIRING



7.5 Large Carolina Design

Figures 7.13 to 7.16 illustrate the maximum attainable boiler load for PC and CWF firing for the oil-designed large Carolina unit.

Due to the rectangular plan of the Carolina design the heat input per burner must be limited to ensure against flame impingement of the rearwall. This results in a maximum attainable load of 78% on PC firing and 76% on CWF firing. The following maximum attainable loads are a result of the increased slagging potential of PC and CWF.

Fuel	PAHRR	Max.Attainable Load Furn. Liber'n.	BZHRR
High Ash PC	97%	74%	88%
Low Ash PC	98%	74%	88%
High Ash CWF	95%	71%	87%
Low Ash CWF	95%	71%	87%

The furnace exit gas temperature limitation results in a maximum attainable boiler load of 68% on PC firing and 67% on CWF firing.

7.5 Large Carolina Design - Cont'd.

The tight side spacing of the reheater outlet bank results in severe limitation of boiler load. In order to keep the flue gas temperature at acceptable levels the maximum attainable load is 42% on PC firing and 44% on CWF firing. Gas recirculation will be used to shift absorption from the furnace to the convective heat transfer surface at these reduced loads.

As before, the need for erosion barriers for high ash fuel firing leads to higher unit deration than for low ash fuel firing.

The following boiler loads are attainable based on flue gas velocity limitations.

Fuel	Flue Gas Limited Max. Attainable Boiler Loads
High Ash PC	48%
Low Ash PC	62%
High Ash CWF	45%
Low Ash CWF	53%

FIGURE 7.13 LARGE CAROLINA
MAX ATTAINABLE LOAD VS
PERFORMANCE LIMITS
FOR HIGH ASH P.C. FIRING

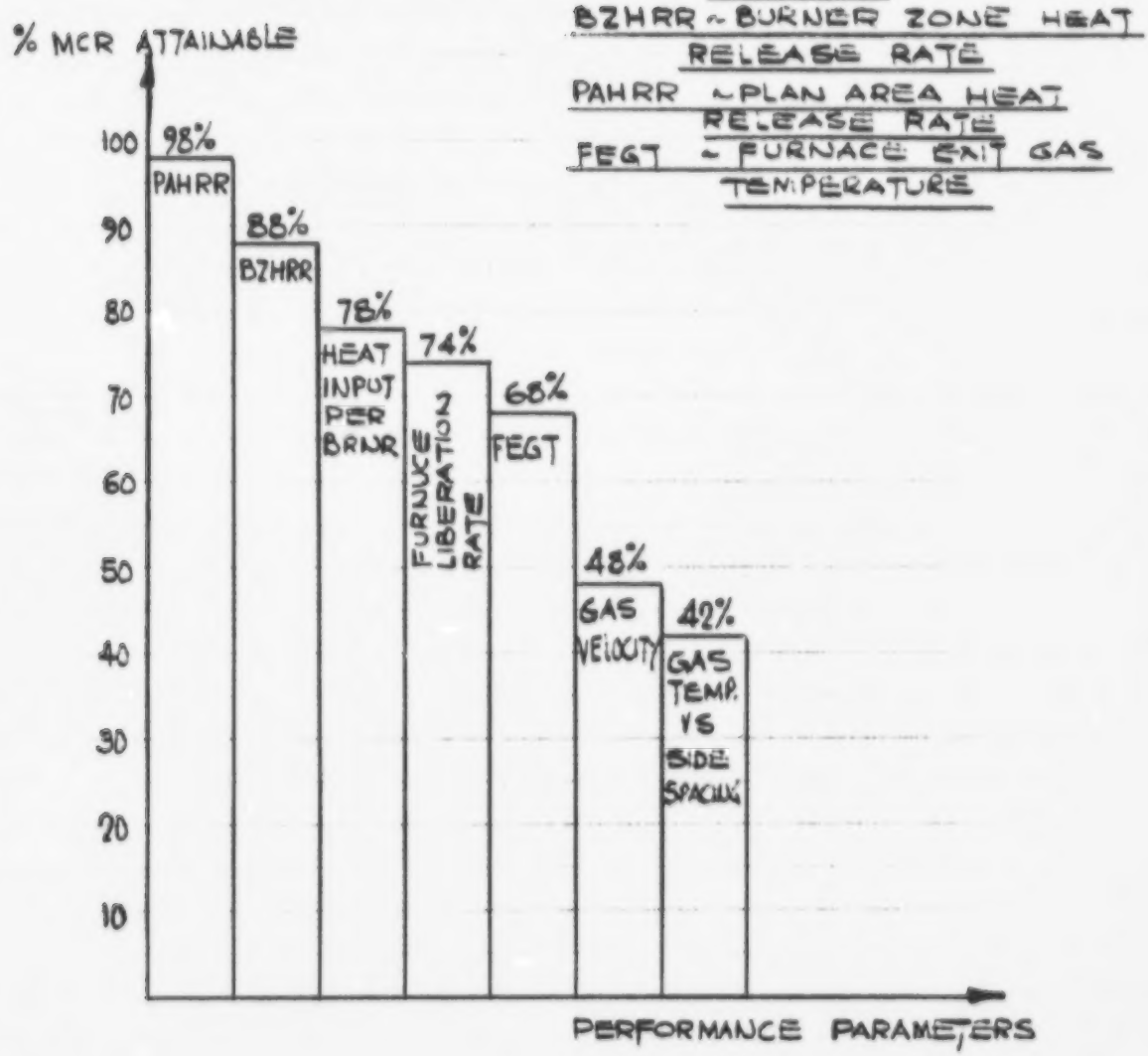


FIGURE 7.14 LARGE CAROLINA MAX. ATTAINABLE LOAD VS PERFORMANCE LIMITS FOR LOW ASH P.C. FIRING

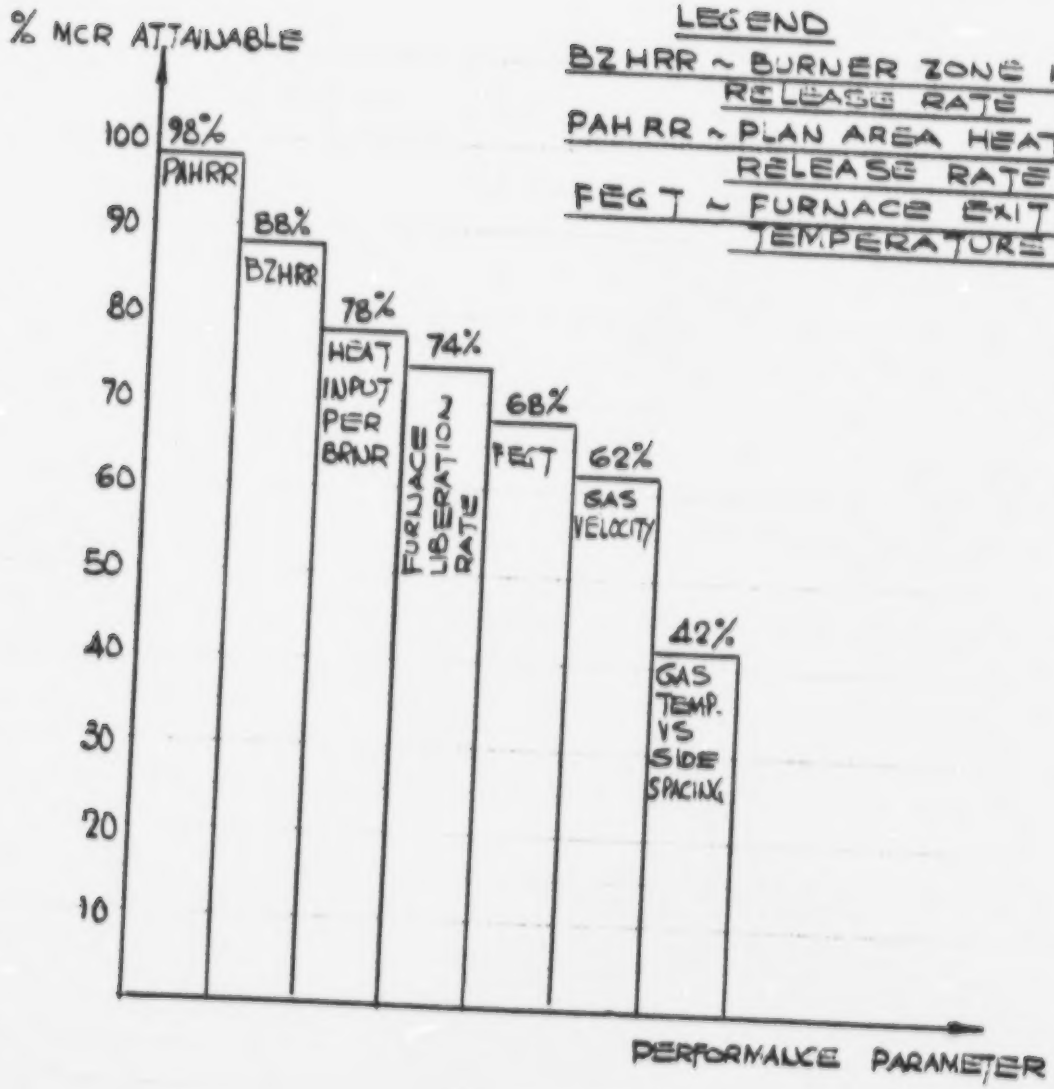


FIGURE 7.15 LARGE CAROLINA
MAX. ATTAINABLE LOAD VS
PERMISSABLE LIMITS
FOR HASH CWF FIRING

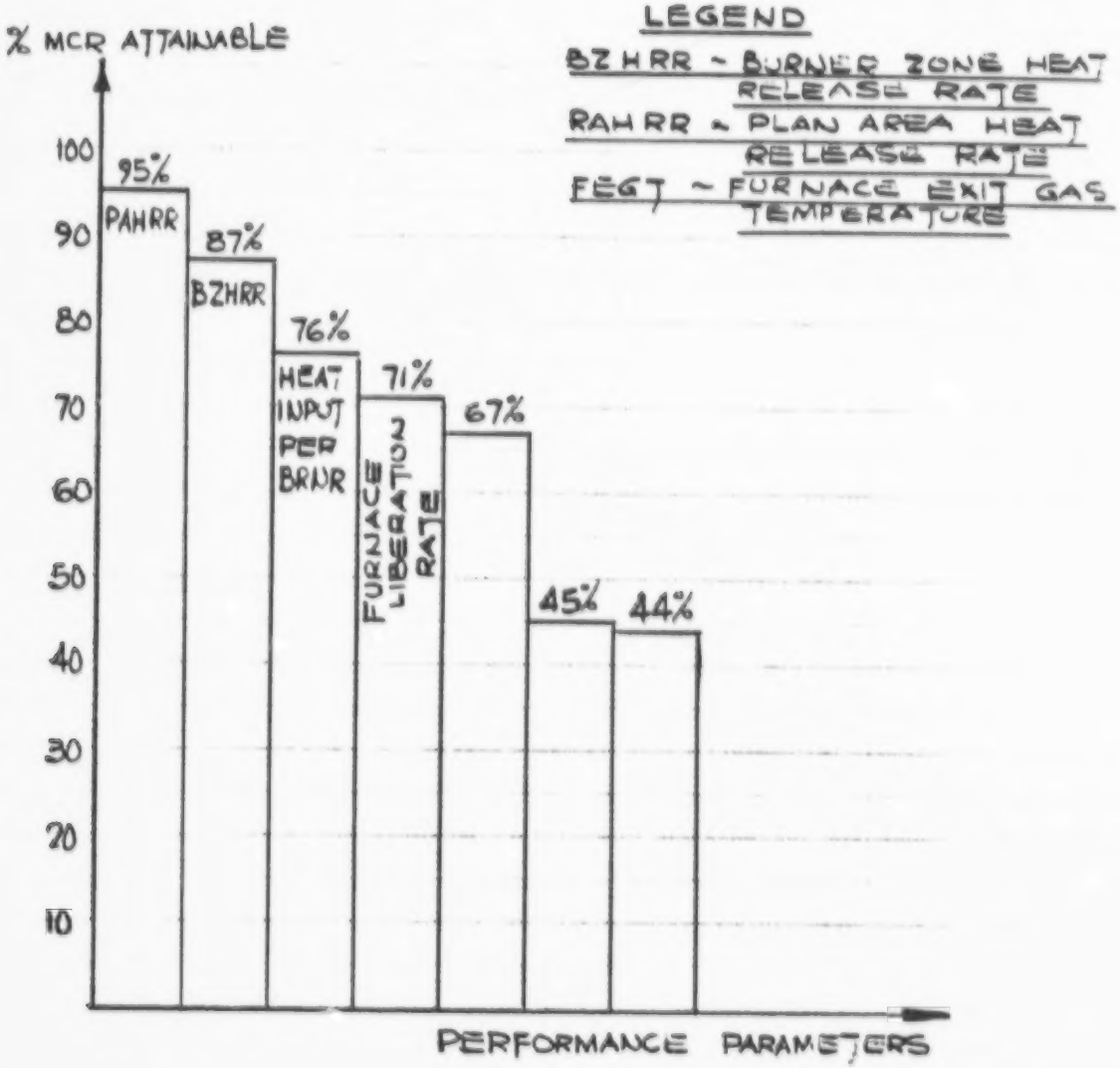
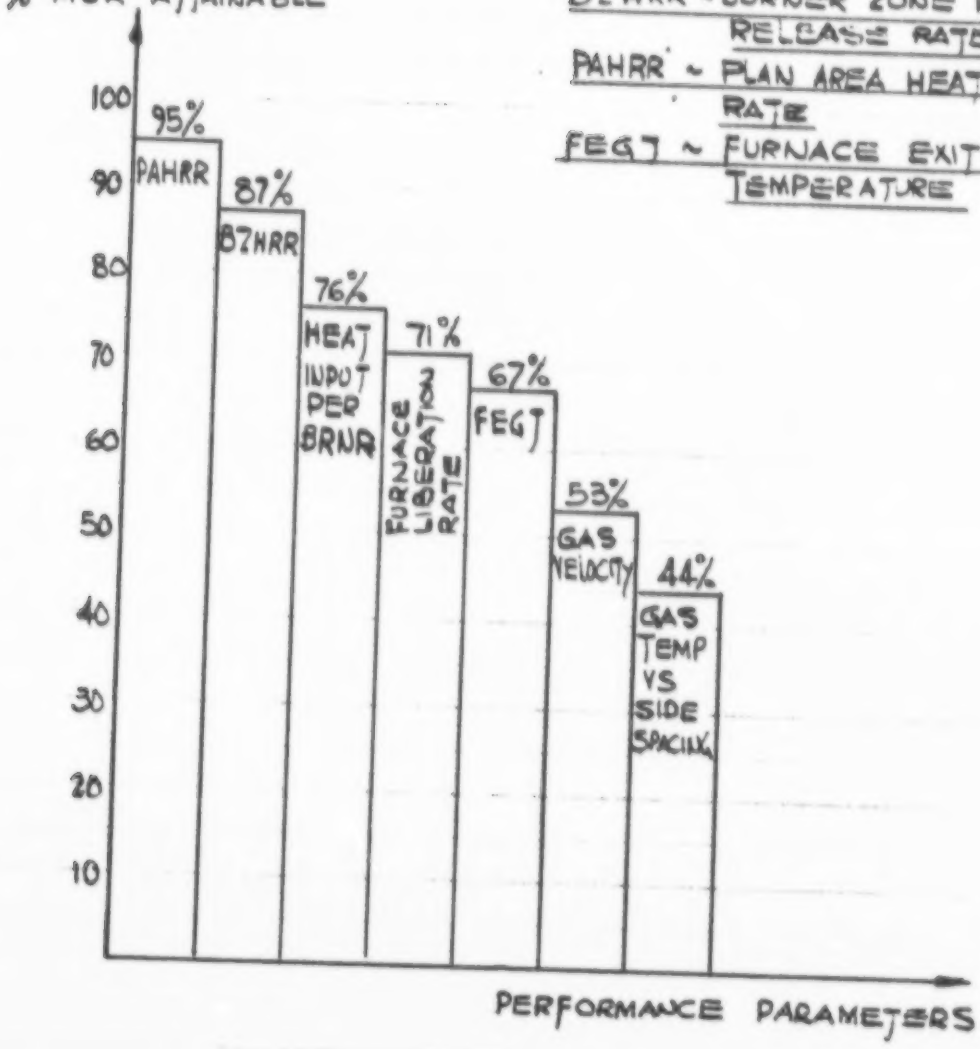


FIGURE 7.16 LARGE CAROLINA
MAX ATTAINABLE LOAD
VS PERFORMANCE LIMITS
FOR LASH C.W.F FIRING

LEGEND
BZHRR ~ BURNER ZONE HEAT RELEASE RATE
PAHRR ~ PLAN AREA HEAT RELEASE RATE
FEGT ~ FURNACE EXIT GAS TEMPERATURE



8.0 Auxiliary Equipment Consideration

Converting an oil designed unit to fire PC or CWF will impact the selection and operation of equipment such as fans, regenerative airheaters and sootblowers. Firing PC fuel presents special problems. Sufficient room must be available for pulverizers, primary air fans and coal pipes. The total air necessary for combustion of the PC fuel must be divided into primary and secondary air flows. The primary air quantity is extracted from the total air flow at the regenerative airheater exit and passed through pulverizers by 'hot' primary air fans. This primary air is used to dry and transport the pulverized coal particles to the furnace. This obviously results in substantial additions of ductwork to connect this new primary air system to the boiler. Additional fans to supply seal air for the pulverizers are also required.

As the intent of this study is to evaluate the conversion potential of oil-designed units to coal/water slurry fuel, the bulk of the investigation will be centered around the impact on the auxiliary equipment associated with firing coal/water slurry.

8.1 Small Oil Fired Boiler Designs

These units normally have one forced draft fan,

8.1 Small Oil Fired Boiler Designs (cont'd)

one steam coil airheater and one regenerative air preheater. They operate with a pressurized furnace and do not utilize ID fans. However, for CWF firing, pressurized operation is not generally practised due to the presence of ash fines which create a need for an induced draft fan for balanced draft operation and impact the operating duty of the forced draft fan.

8.1.1 Forced Draft Fan

The following table shows the fan selection criteria for oil firing:

	Net Operating Load	Test Block
Capacity (lb/hr)	689,000	826,000
Fluid Temp. (deg. F)	80	105
Static Pressure (in Wg)	20	25

Firing the units with coal/water slurry would result in the following operating fan duties: (assuming an ID fan has been added to the unit)

	Boiler Load		
	100%	41%	60%
Capacity (lb/hr)	795,000	351,000	466,000
Fluid Temp. (deg. F)	80	80	80
Static Pressure (in Wg)	11	6	7

8.1.1 Forced Draft Fan (cont'd)

As can be seen from these duties, if the boiler were capable of full load on CWF firing, which is however not the case, the fans would be operating very close to their test block capacity. The FEGT - limited load of 41% for the small El Paso unit results in a fan duty well within the capabilities of the fan, however, the turndown available will be severely limited.

The 60% maximum attainable load on CWF firing for the small Carolina unit is goverened by side spacing vs gas temperature. As can be seen this duty is well within the capabilities of the fan. Operating the fans at well below their design capability could result in some fan instability problems. A detailed investigation of the fan's operating characteristics would be necessary to ensure it could operate acceptably under these conditions.

8.1.2 Regenerative Air Preheaters

The regenerative air preheaters were selected based on the following full load duty on oil firing:

	100% load - Oil Fired
Gas weight to AH (lb/hr)	705,950
Air weight lvg AH (lb/hr)	643,850
Gas temp. to AH (deg. F)	737
Gas temp. lvg AH (deg F) (uncorrected for leakage)	300
Air temp. to AH (deg. F)	80
Air temp. lvg AH (deg. F)	605

Coal/water firing would result in the following airheater performance:

	Boiler Load		
	100%	41%	60%
Gas weight to AH (lb/hr)	848,820	349,400	495,800
Air weight lvg AH (lb/hr)	749,470	308,480	441,200
Gas temp. to AH (deg. F)	764	600	650
Gas temp. lvg AH (deg. F) (uncorrected for leakage)	322	269	285
Air temp. to AH (deg. F)	80	110 (SCAH on)	90
Air temp. lvg AH (deg. F)	630	518	530

8.1.2 Regenerative Air Preheaters (cont'd)

As can be seen from this performance, the regenerative airheater has more surface than necessary for CWF firing. The FEGT limited load of 41% on CWF firing for the small El Paso design produces an air exit temperature of 518 deg. F and the need for steam coil air preheating for cold end corrosion protection. The 60% CWF fired load for the small Carolina results in an air exit temperature of 530 deg. F and the need for steam coil air preheating. Although this is not the optimum situation this performance is acceptable.

8.1.3 Sootblowers

When firing PC or CWF in the oil designed boilers, more sootblowers will be required due to the increased ash content of the fuel. This ash leads to slagging in the furnace and fouling of the convective surfaces in the boiler. The following summarizes the typical quantity of additional sootblowers needed for the El Paso and Craolina boiler styles in this size range: (Ref. Fig. 8.1 - 8.4)

	El Paso		Carolina	
Sootblower Type	Oil	CWF	Oil	CWF
Retractable	16	22	14	24
Wallblower	-	8	-	8
Arch Wallblower	-	2	-	2

8.2 Large Boiler Designs

The large boiler designs selected incorporate balanced draft firing and consequently require fans to induce draft. This may not be the case on all existing boilers. The large units have two forced draft fans, two induced draft fans, two regenerative air preheaters and two steam coil air preheaters. The large Carolina unit also uses two gas recirculation fans.

8.2.1 Forced Draft Fans

The following table shows the forced draft fan selection criteria for full load oil firing:

	Net Operating Load	Test Block
Capacity (lb/hr/fan)	709,000	851,000
Fluid Temp. (deg. F)	80	105
Static Pressure (in Wg)	13	16.25

Firing the large units with high ash coal/water slurry results in a gas velocity limited maximum load of 53% for the El Paso style unit and a gas temperature vs side spacing limited maximum load of 44% for the Carolina style. The following operating fan duties would result:

8.2.1 Forced Draft Fans (cont'd)

	Boiler Load		
	100%	53%	44%
Capacity (lb/hr/fan)	795,000	472,600	411,000
Fluid Temp. (deg. F)	80	87	96
Static Pressure (in Wg)	15	9.0	8.0

As can be seen, these operating loads would pose no problems for these fans. The additional option of using only one forced draft fan instead of two provides extra turndown capability.

8.2.2 Induced Draft Fans

The following table shows the induced draft fan selection criteria for full load oil firing:

	Net Operating Load	Test Block
Capacity (lb/hr/fan)	773,000	912,000
Fluid Temp. (deg. F)	343	368
Static Pressure (in Wg)	20.0	25.0

Firing high ash coal/water slurry in the large units would result in the following operating fan duties:

	Boiler Load		
	100%	53%	44%
Capacity (lb/hr/fan)	923,700	522,000	445,200
Fluid Temp. (deg. F)	349	312	300
Static Pressure (in Wg)	29.0	9.0	7.0

8.2.2 Induced Draft Fans (cont'd)

As illustrated above the oil-designed induced draft fans are incapable of full load on CWF firing. The possibility of fan instability is definitely present for the Carolina maximum load of 44%. A detailed investigation of the fan operating characteristics would be necessary during a site-specific conversion feasibility study.

8.2.3 Gas Recirculation Fans

The large Carolina unit uses two gas recirculation fans for control of reheater steam temperature. The fan selection criteria for oil firing is as follows:

	Net Operating Load	Test Block
Capacity (lb/hr/fan)	133,100	157,100
Fluid Temp. (deg. F)	700	725
Static Pressure (in Wg)	5.0	6.25

Coal/water slurry firing results in the following gas recirculation fan operating duties:

8.2.3 Gas Recirculation Fans (cont'd)

	Boiler Load		
	60%	53%	44%*
Capacity (lb/hr/fan)	90,700	81,211	69,000
Fluid Temp. (deg. F)	685	650	605
Static Pressure (in Wg)	2.5	2.0	1.6

* This duty is based on a reduced reheat steam exit temperature.

The gas recirculation fans selected for oil firing will be adequate for CWF firing.

8.2.4 Regenerative Air Preheaters

The regenerative air preheaters were selected based on the following full load duty on oil firing:

	100% load - Oil Fired
Gas weight to AH (lb/hr each)	725,515
Air weight lvg AH (lb/hr each)	661,695
Gas temp. to AH (deg. F)	671
Gas temp. lvg AH (deg. F) (uncorrected for leakage)	360
Air temp. to AH (deg. F)	80
Air temp. lvg AH (deg. F)	457

8.2.4 Regenerative Air Preheaters (cont'd)

Firing coal/water slurry would result in the following airheater performance:

	Boiler Load		
	100%	53%	44%
Gas weight to AH (lb/hr ea)	875,885	475,000	400,200
Air weight lvg AH (lb/hr ea)	821,207	425,600	366,000
Gas temp. to AH (deg. F)	660	620	600
Gas temp. lvg AH (deg. F) (uncorrected for leakage)	364	332	322
Air temp. to AH (deg. F)	80	87	96
Air temp. lvg AH (deg. F)	451	440	430

These regenerative airheaters provide marginal performance. The secondary air temperatures may not be high enough to support stable combustion on CWF firing. Some preheat of secondary air by steam coils may be necessary.

8.2.5 Sootblowers

As with the small units, firing PC or CWF in the oil designed boilers will require more sootblowers to ensure the unit remains clean. The following summarizes the typical quantity of additional sootblowers needed for the El Paso and Carolina boiler styles in this size range:

	El Paso		Carolina	
Sootblower Type	Oil	CWF	Oil	CWF
Retractable	24	36	20	26
Wallblower	-	8	-	8
Arch Wallblower	-	2	-	2

Ref. Fig. 8.5 - 8.8

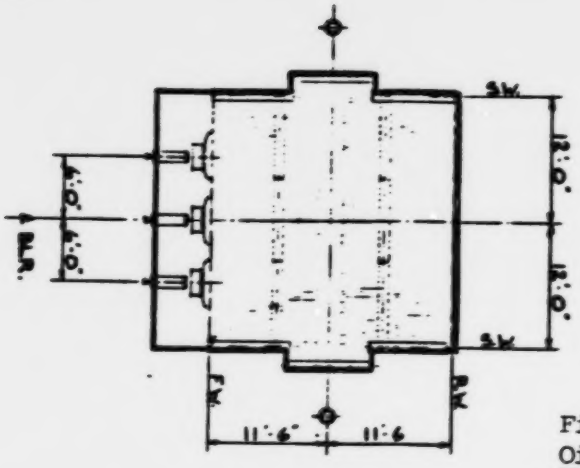
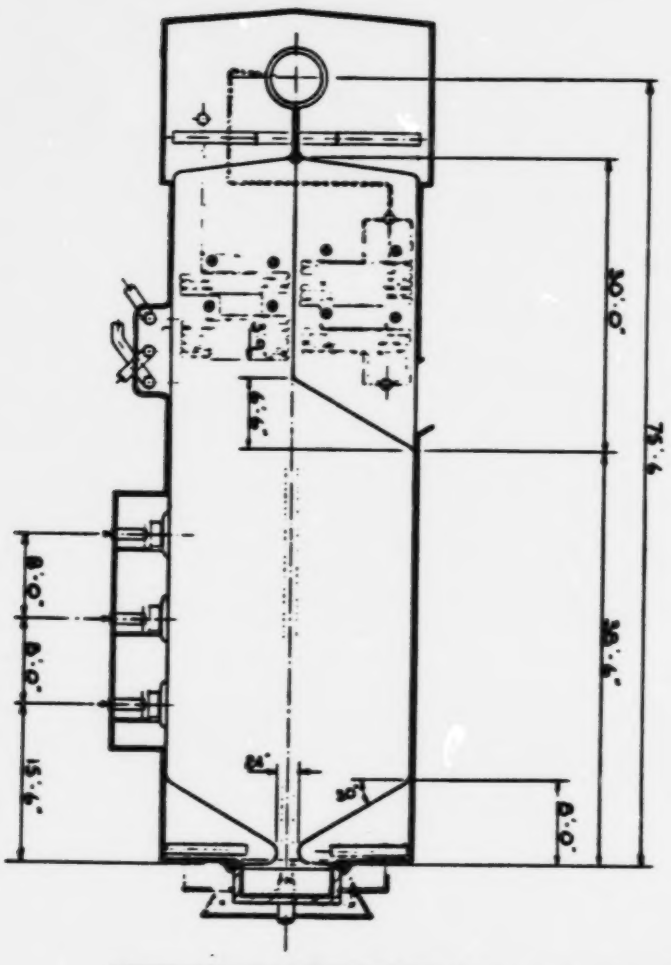


Figure 8.1 Sootblower for Oil Fired Small El Paso Design



- Retractable Sootblower (one in each Sidewall)

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	CUSTOMER D.S.S.C. COAL/WATER FUEL DERATING STUDY
	DRAWN E.D.V. DATE 86 FILE No. 14 SQ 23440 1-9134 REV.
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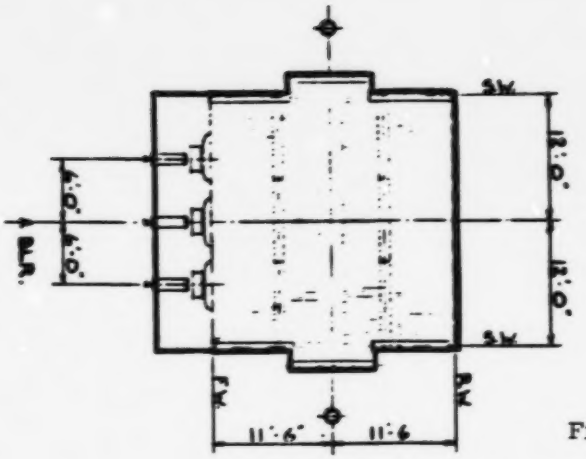
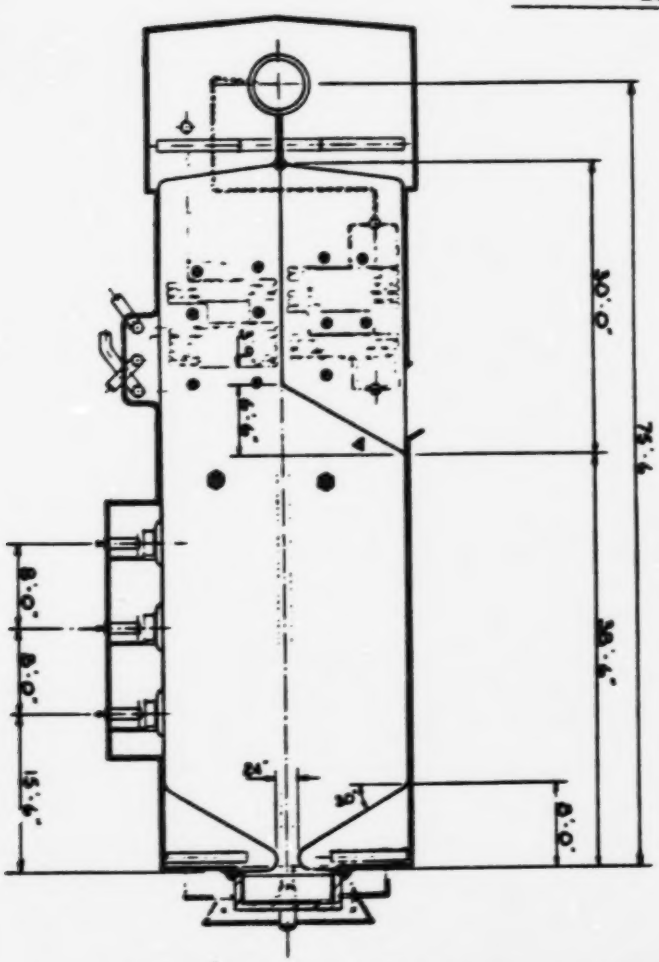


Figure: 8.2 Sootblower for Coal Fired Small El Paso Design



- retractable sootblower (one in each sidewall
- wallblower (one in each wall)
- arch wall blower (one in each sidewall

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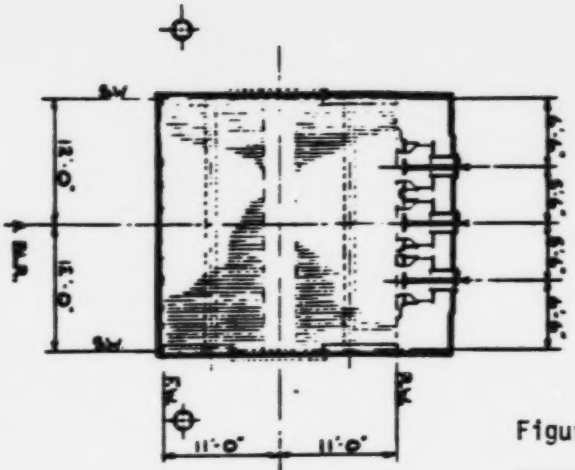
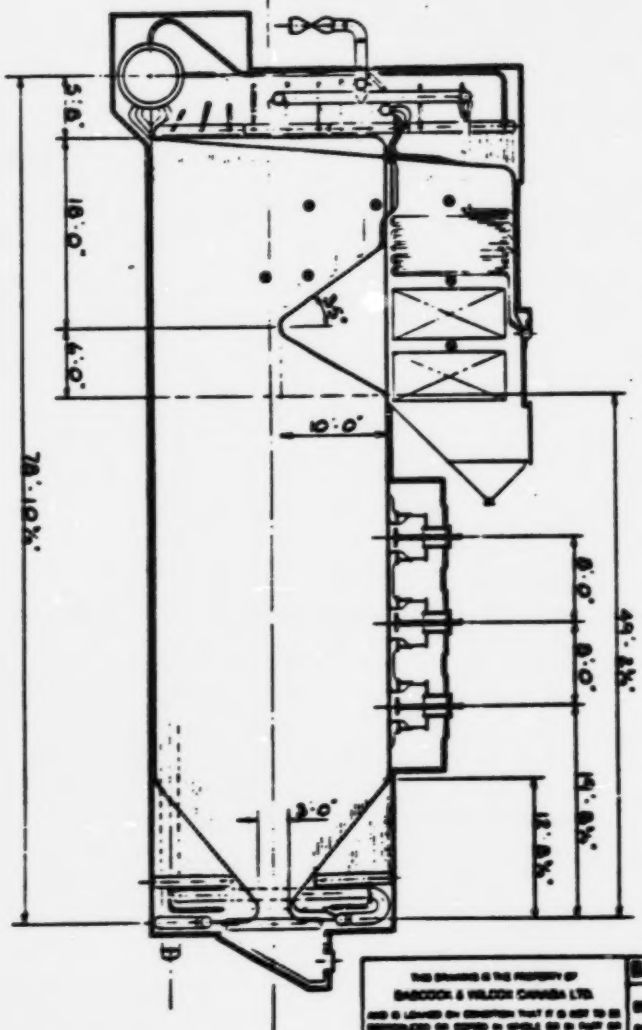


Figure: 8.3 Sootblowers for Oil-Fired Small Carolina Design



- Retractable sootblower (one in each sidewall)

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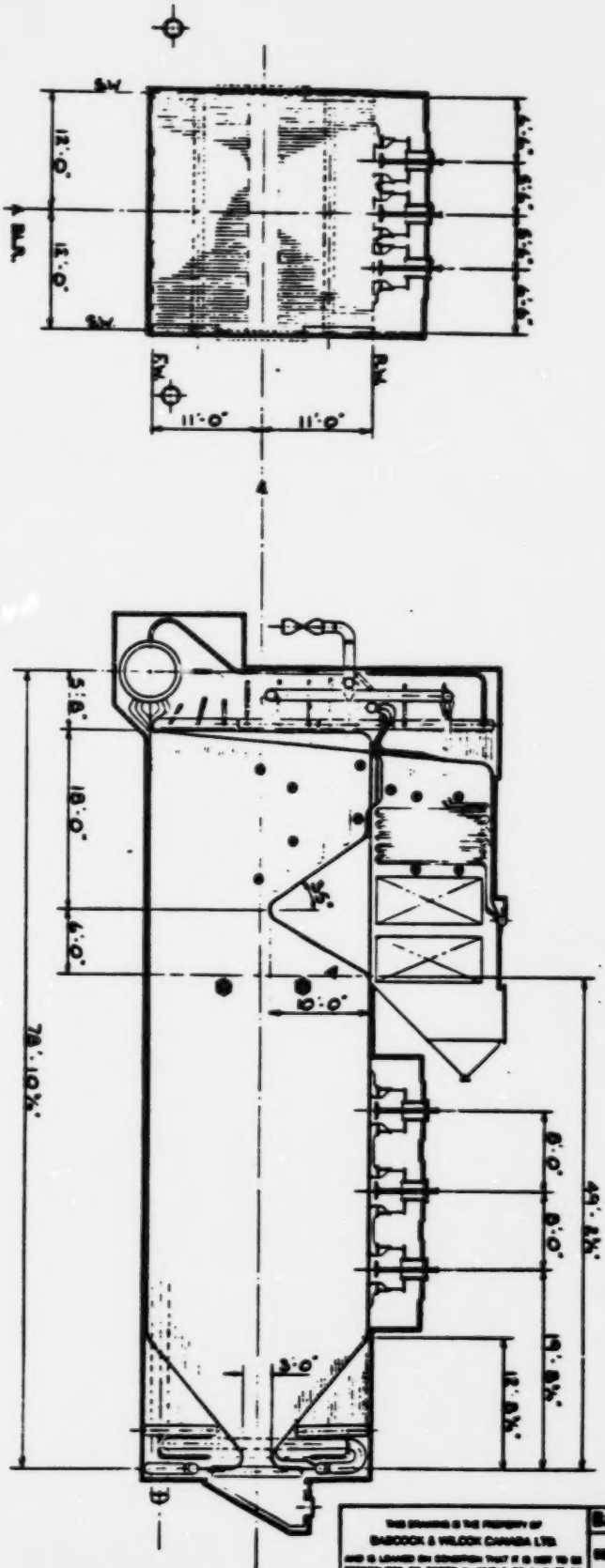

Figure: 8.4 Sootblowers for Coal Fired Small Carolina Design

- retractable sootblower (one in each sidewall)
- Wallblower (one in each wall)
- Arch Wallblower (one in each sidewall)

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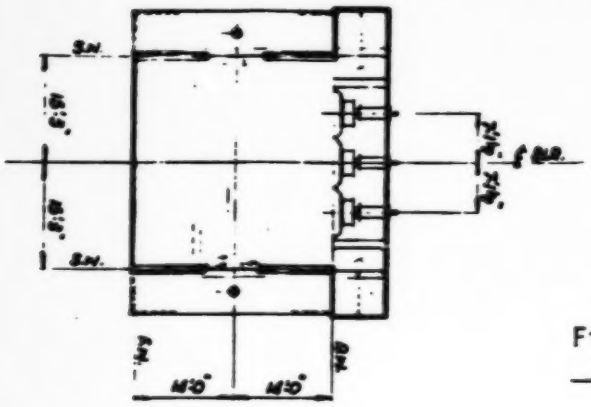
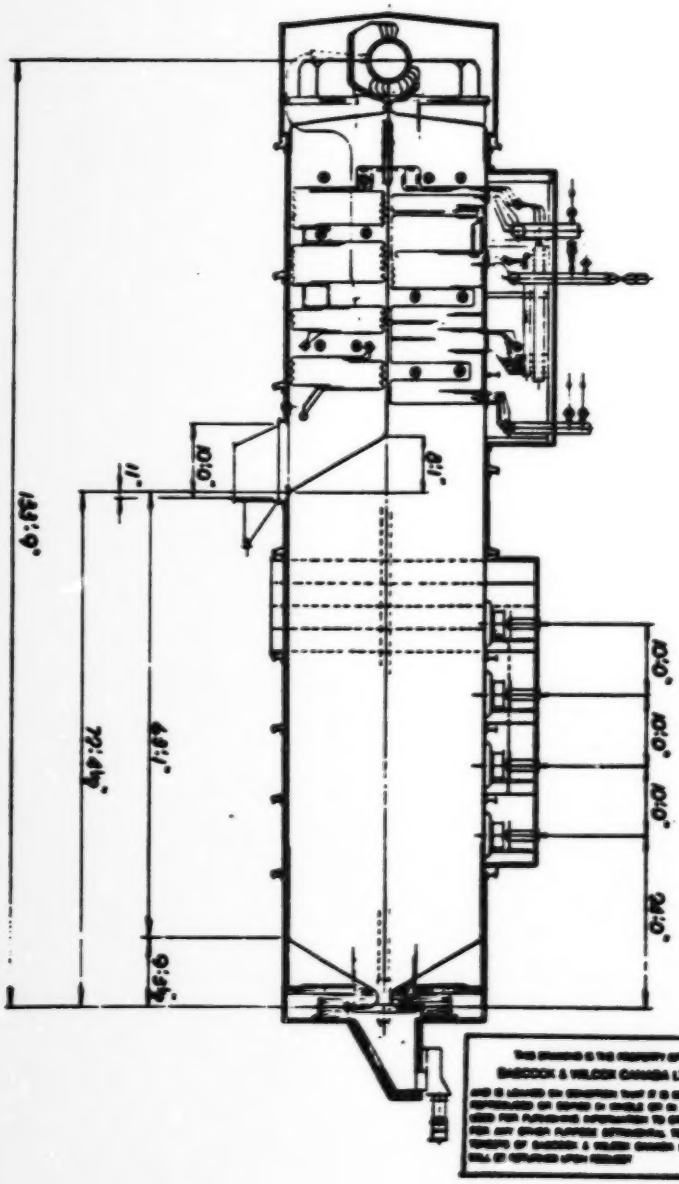


Figure: 8.5 Sootblower for Coal-Fired Large El Paso Design



- retractable sootblower (one in each sidewall)

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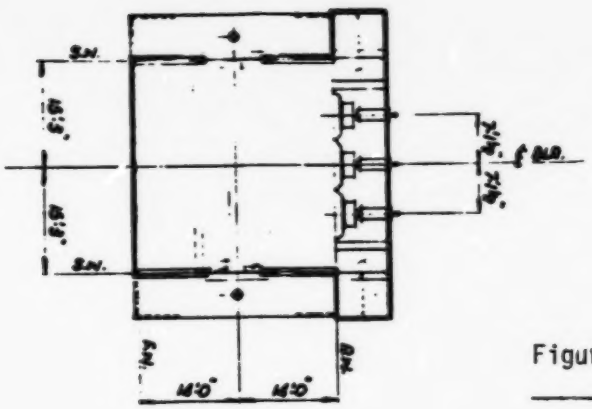
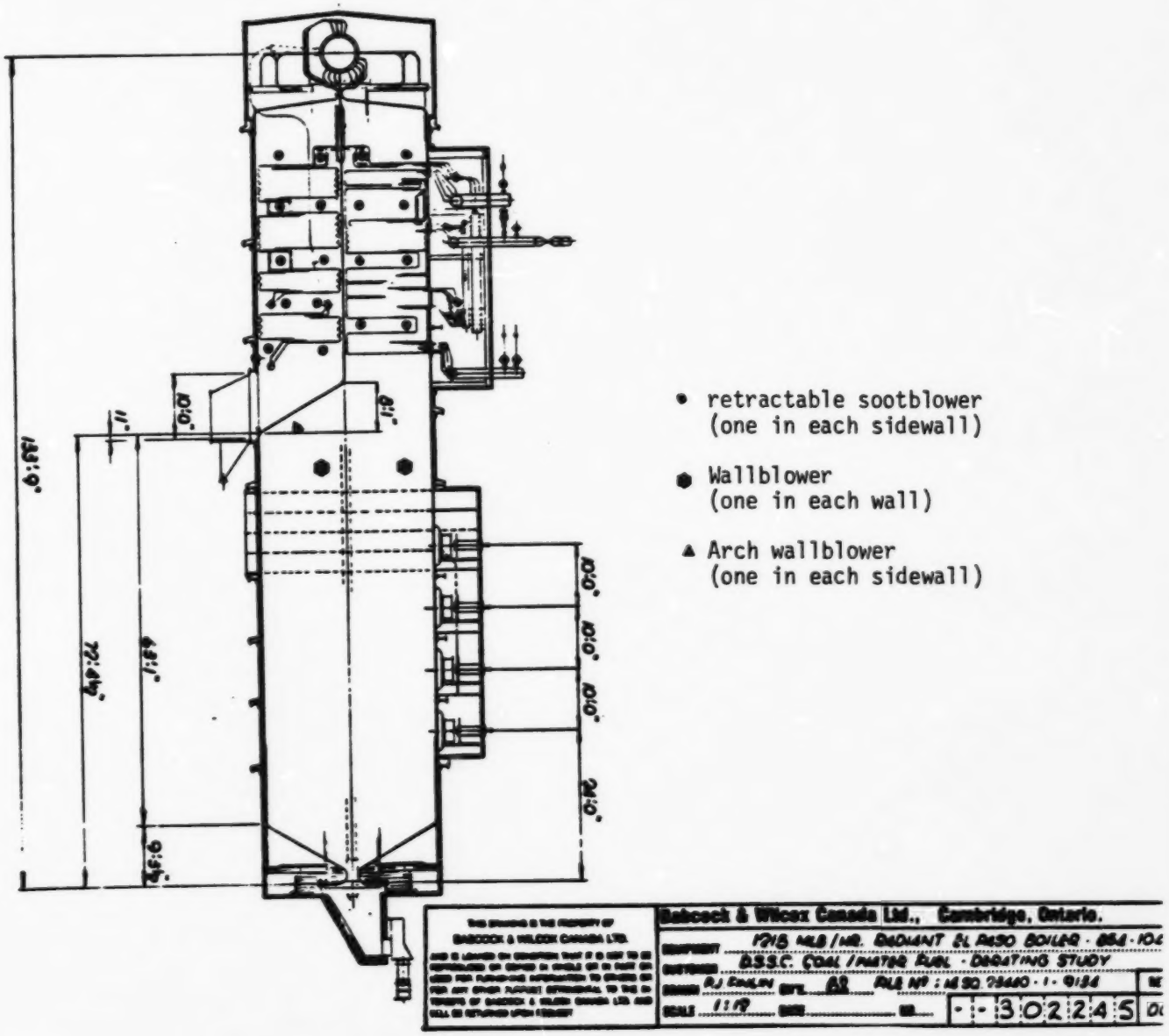


Figure: 8.6 Sootblower for Coal-Fired Large El Paso Design


• retractable sootblower (one in each sidewall)
⬢ Wallblower (one in each wall)
▲ Arch wallblower (one in each sidewall)
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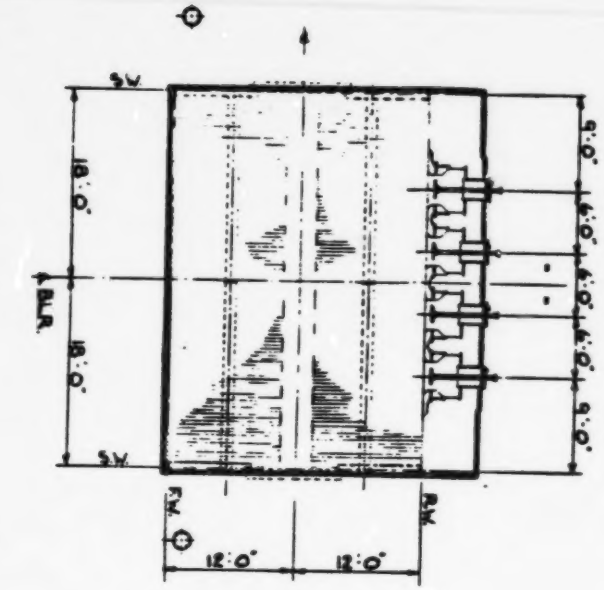
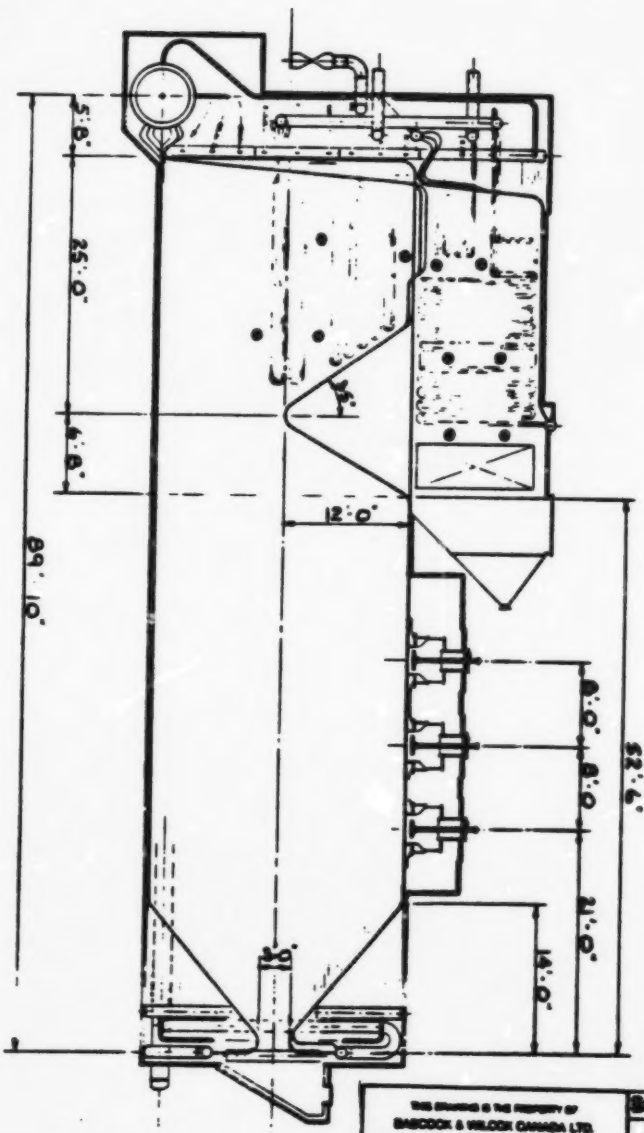


Figure: 8.7 Sootblower for Oil-Fired Large Carolina Design



- retractable sootblower (one in each Sidewall)

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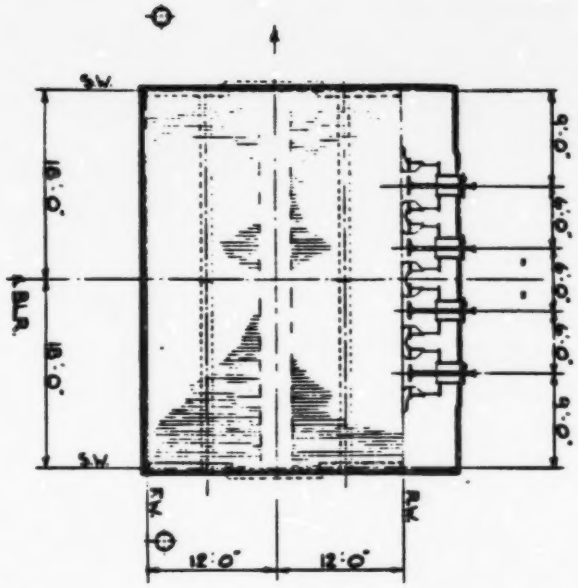
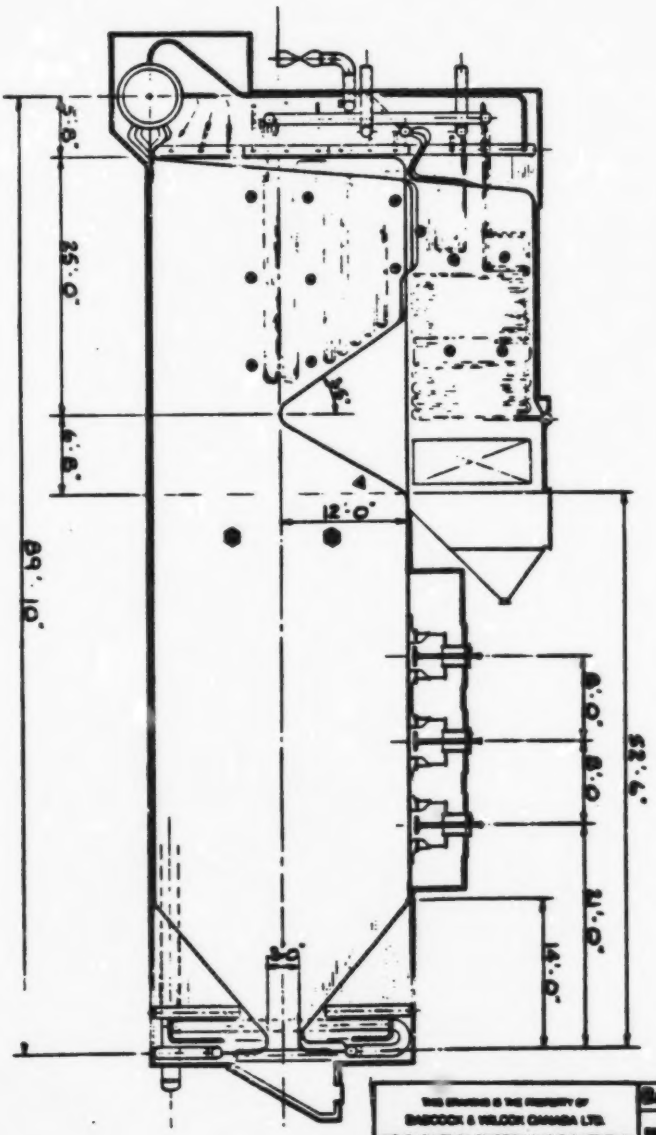


Figure: 8.8 Sootblowers for Coal-Fired Large Carolina Design



- retractable sootblower (one in each sideawall)
- Wallblower (one in each wall)
- arch wallblower (one in each sidewall)

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Babcock & Wilcox Canada Ltd., Cambridge, Ontario.

EQUIPMENT 1215 mm/HR RADIANT CAROLINA BOILER

CUSTOMER DOE: COAL/WATER FUEL - DERATING STUDY

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9.0 Modifications to Reduce Derations

9.1 General

Unit modifications can be made to reduce the derating effects of firing CWF in an oil designed boiler. However, consideration should be given to limit these modifications to changes that will not seriously degrade the unit's capability on oil firing.

A major concern when firing CWF is to limit the flue gas temperature entering the convective heat transfer surface to below the ash fusion temperature. The obvious method to accomplish this is to limit the heat input to the furnace (i.e. derate the boiler). In some cases, however, it is not economically feasible to operate the unit at these reduced loads.

One method available to reduce this furnace exit gas temperature (FEGT) is gas tempering. With this technique recirculated gas extracted at the economizer exit is introduced to the furnace just below the furnace exit plane. This cooler flue gas reduces the gas temperature entering the convective heat transfer surface without affecting furnace heat absorption. This option is obviously only practical

9.1 General (cont'd)

for units using gas recirculation for reheat steam temperature control. A detailed site specific investigation would have to be performed to assess the impact of gas tempering on the unit and its auxiliaries.

Another method to reduce the FEGT is to place more heating surface in the furnace. One way this can be accomplished is by using watercooled wingwalls located in the upper furnace. This modification would require a detailed study of the boiler circulation system to ensure natural circulation is maintained and cyclone steam separators are not overloaded. Additional feeders and risers would be required to supply water to the wingwall and return it to the drum. It must be stressed that this technique requires a detailed study.

If the load-limiting performance criteria is flue gas velocity or gas temperature vs side spacing, the tube spacing can be altered by removing alternate tube rows or replacing entire banks of tubes.

9.2 Small El Paso Design

The maximum attainable load on CWF firing for this unit is determined by the allowable FEGT at the tightly spaced (9") furnace exit. If the spacing of this superheat bank could be increased to 18" (perpendicular to the gas flow) the unit could be operated at 55% for high ash CWF firing and 61% for low ash CWF firing. This is a result of the maximum attainable boiler load now being limited by allowable flue gas velocity and allowable furnace heat liberation rate respectively. Additional superheat surface would probably have to be added elsewhere in the boiler to provide sufficient heat absorption to make superheater exit temperature.

9.3 Large El Paso Design

For high ash CWF firing, the gas free flow area entering the primary superheater bank at the top of the downpass limits the maximum attainable boiler load to 53%. If pressure part changes could be made to increase the free flow area, and thereby reduce the gas velocity entering this bank the unit load could be increased to the FEGT limited load of 62%.

This unit might be a candidate for more unique solutions to reduce the FEGT; such as watercooled wing-

9.3 Large El Paso Design (cont'd)

walls located in the upper furnace. Although the potential is present to increase the unit load beyond 62%, detailed study work would be necessary.

9.4 Small Carolina Design

The tube side spacing of the primary superheater bank at the top of the downpass limits the maximum attainable boiler load during CWF firing. This 4" spacing could be increased to permit the boiler to be fired at a higher load. Increasing the side spacing of this bank would also eliminate the limitation due to flue gas velocity. The maximum boiler load cannot be increased above 79% for CWF firing due to furnace exit gas temperature limitations.

9.5 Large Carolina Design

This unit is particularly suitable for pressure part modifications due to the severe load deration resulting from the tight side spacing of the first reheat bank. Removing every other row of the reheater bank may allow the unit load to be increased to the FEGT - limited load of 67% for CWF firing. This will, of course, result in the required addition of reheat surface in some other area.

9.5 Large Carolina Design (cont'd)

The potential for further reduction in this unit's deration is present due to the fact that this unit uses gas recirculation for reheat steam temperature control. Directing some recirculated gas to tempering ports located at the furance exit could reduce the temperature of the flue gas leaving the furance without affecting the furnace heat absorption.

10.0 Discussion of Results

10.1 Boiler

The maximum attainable boiler loads for each boiler model for PC and CWF firing are summarized in Figures 10.1 to 10.4. The major boiler load limiting parameters were furance exit gas temperature, flue gas velocity and flue gas temperature vs tube side spacing.

When considering Figure 10.1 it is noted that the small El Paso model is the most severely derated boiler with its maximum attainable load of 41% for CWF firing and 42% for PC firing. This is a reflection of the fact that the El Paso design standards are primarily for oil and gas fired units. This results in a 'tighter' furnace size and consequently lower furnace residence times and higher furnace exit gas temperatures.

The large Carolina model was also severely derated with maximum attainable boiler loads of 44% and 42% for CWF and PC firing respectively. This severe deration is a result of tight tube side spacing at the entrance to the first reheater bank. Although this model appears to be heavily derated it is probably the unit style and size that could most benefit from modifications. "Opening up" the tube

10.1 Boiler (cont'd)

spacing at this bank and using recirculated flue gas to temper down the furnace exit gas temperature could substantially increase the attainable boiler load for CWF and PC firing. The fact that the Carolina boiler design standards were generated for primarily solid fuels results in the potential for big gains in attainable loads from unit modifications.

The large El Paso model is load limited by allowable flue gas velocity to:

61% for low ash CWF

53% for high ash CWF

63% for low ash PC

57% for high ash PC

This unit could not be fired above the FEGT-limited load of 62% without major pressure part changes to increase the heat absorbing surface in the furnace.

The small Carolina model is capable of attaining 60% load for CWF firing and 58% load for PC firing. Its maximum load is limited by flue gas temperature vs tube side spacing criteria at the first downpass primary superheater bank. "Opening up" the spacing of this bank would permit this unit to be fired at 79% load for CWF firing. This model design is

10.1 Boiler (cont'd)

particularly conservative because Carolina design standards are intended for solid fuel boilers of larger sizes. This results in a larger than necessary furnace for oil firing, due to physical design limits, and consequently less deration during PC or CWF firing. The design FEGT on oil for this unit is 180 deg. F lower than for the small El Paso unit due to the physical furnace requirements.

10.2 Performance

In cases where the maximum attainable boiler load when firing PC or CWF is below the boiler control range deviations in the steam conditions resulted. For example, for the large Carolina 44% maximum load on high ash CWF firing the following steam conditions result:

superheater steam flow	- 486,000 lb/hr
superheater steam exit temp.	- 900 deg. F
reheater steam flow	- 430,000 lb/hr
reheater steam exit temp.	- 885 deg. F

For boiler loads within the control range satisfactory steam temperatures were obtained for all units with reasonable amounts of attemperator spray. If pressure part changes are made to reduce a unit's deration for CWF firing, care must be

10.2 Performance (cont'd)

taken to ensure against excessive spray quantities. An additional concern when making pressure part changes is the effect these changes will have upon the boilers ability to fire oil.

The additional moisture present in CWF resulted in lower boiler efficiencies. This is of course due to the need to evaporate this additional moisture in the fuel. The following example illustrates the effect of slurrying:

	Full Load Firing PC (high ash)	Full Load Firing CWF (high ash)
dry gas loss	5.343	6.333
water from fuel loss	4.782	7.687
moisture in air loss	0.134	0.158
unburned combustible loss	0.300	0.300
radiation loss	0.224	0.224
unaccounted for losses & manufacturers margin	1.500	1.500
total losses	12.282	16.202
efficiency	87.718	83.798

This decrease in unit efficiency results in firing more fuel for the same heat output. This results in a small increase in flue gas weight at any given load. The small additional deration to go from PC

10.2 Performance (cont'd)

to CWF firing is a result of this drop in unit efficiency.

Research work done by Babcock & Wilcox on firing CWF in various burners under various conditions led to some correlations between excess air levels, volatile matter in fuels and secondary air temperatures. Based upon this experience, the minimum secondary air temperature that could support stable combustion for this specific CWF is estimated to be in the neighbourhood of 500 deg. F. This limitation may result in the need for some form of additional air preheat (i.e. larger steam coil air heaters, duct burners, etc.)

Firing PC or CWF will result in higher NO_x production than firing oil. This is primarily due to the large increase in fuel NO_x due to the large increase in nitrogen content of the PC and CWF. The following illustrates the approximate increase in NO_x to be expected between firing PC at say 60% load and oil at full load:

10.2 Performance (cont'd)

NO_x, ppm/v on dry flue gas gasis

	Small Unit	Large Unit
oil (full load)	180	185
PC (60% load)	510	535

The NO_x formed during CWF firing will be somewhat lower than for PC firing due to the reduction in adiabatic flame temperature. This lower flame temperature will result in a reduction in this formation of the temperature dependent thermal NO_x.

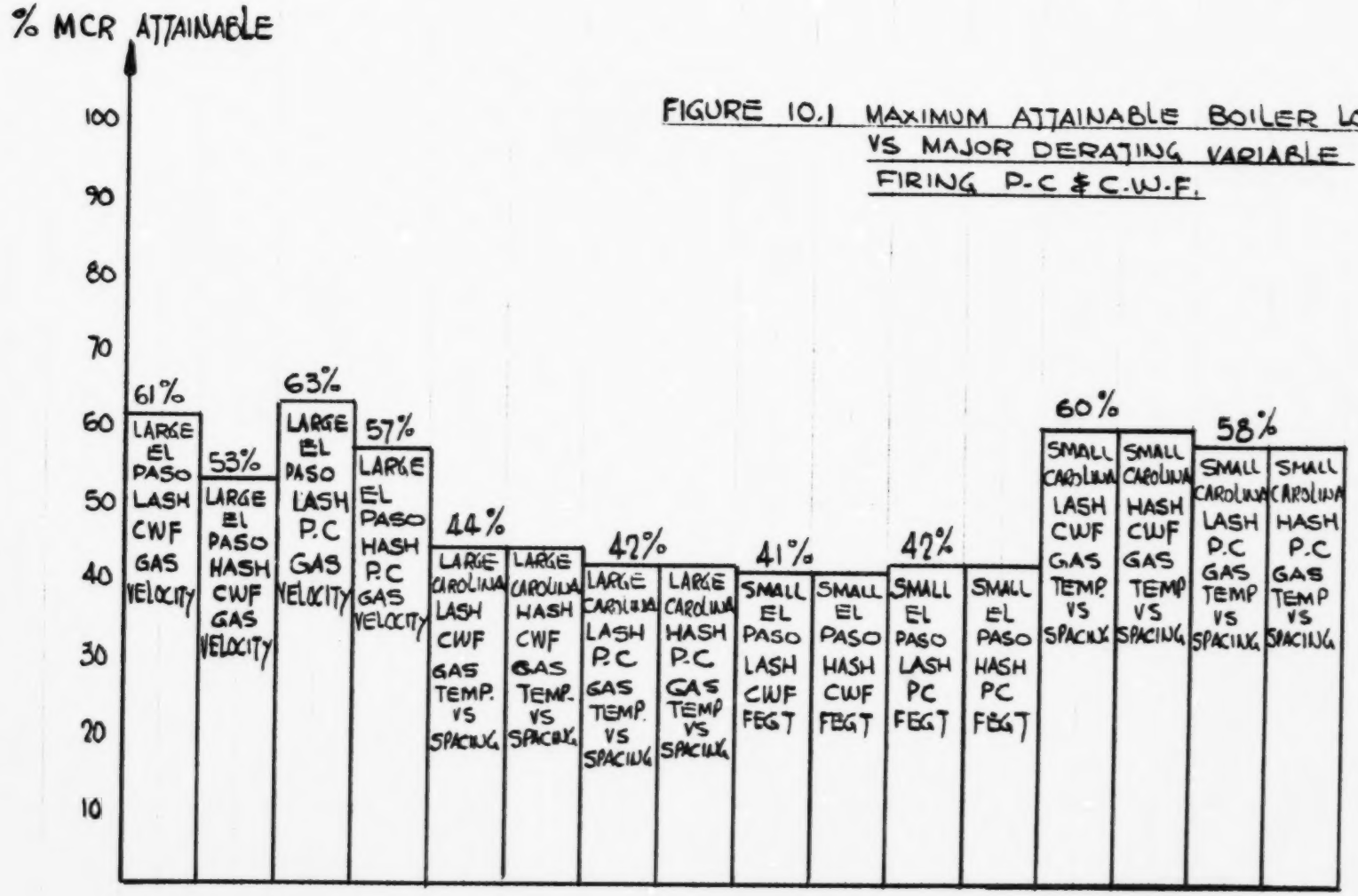

FIGURE 10.1 MAXIMUM ATTAINABLE BOILER LOADS VS MAJOR DERATING VARIABLE FIRING P-C & C.W.F.

LASH = LOW HASH
HASH = HIGH ASH

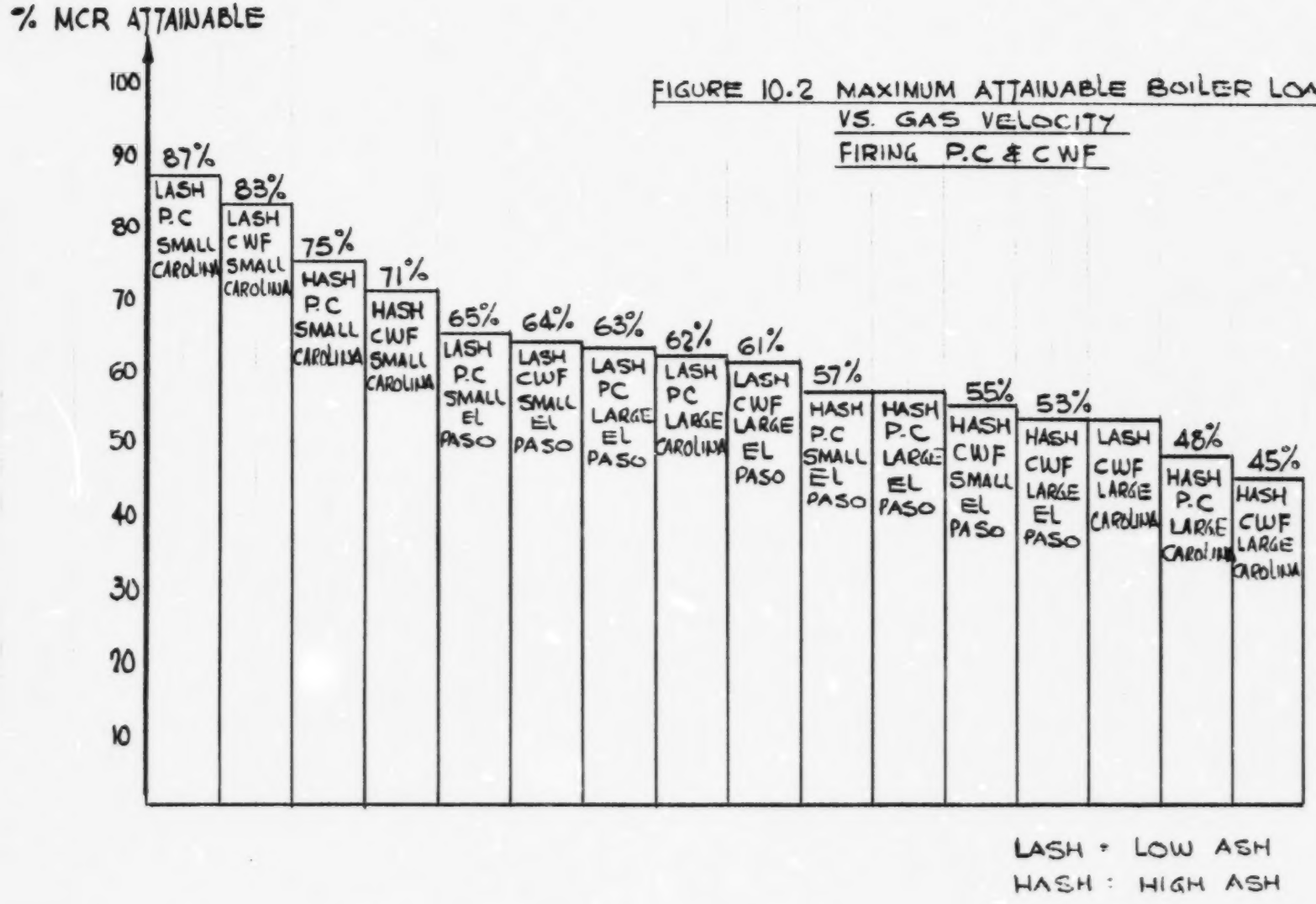

FIGURE 10.2 MAXIMUM ATTAINABLE BOILER LOAD VS. GAS VELOCITY FIRING P.C & C WF

LASH = LOW ASH
HASH = HIGH ASH

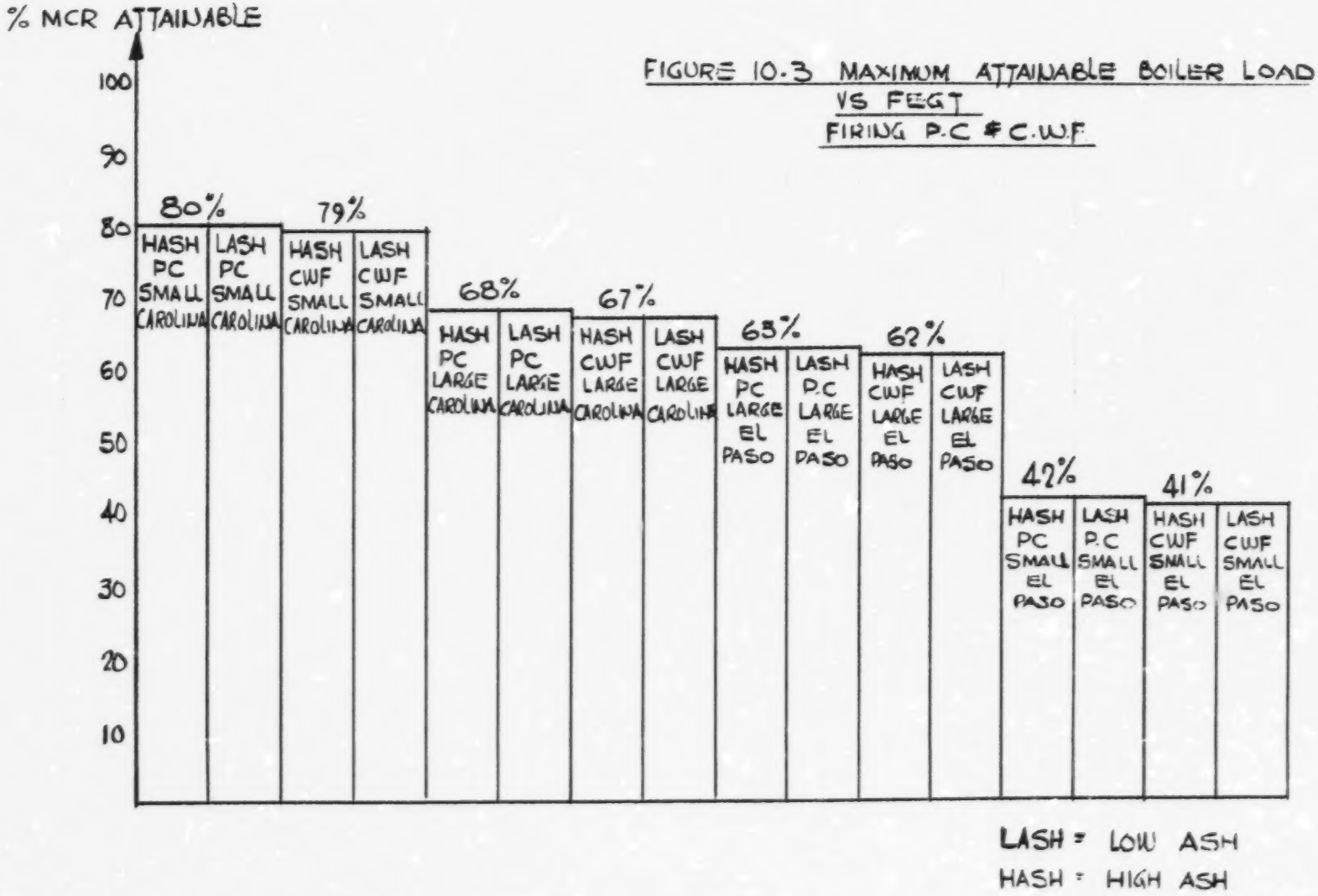

FIGURE 10.3 MAXIMUM ATTAINABLE BOILER LOAD VS FEGT FIRING P.C & C.W.F

LASH = LOW ASH
HASH = HIGH ASH

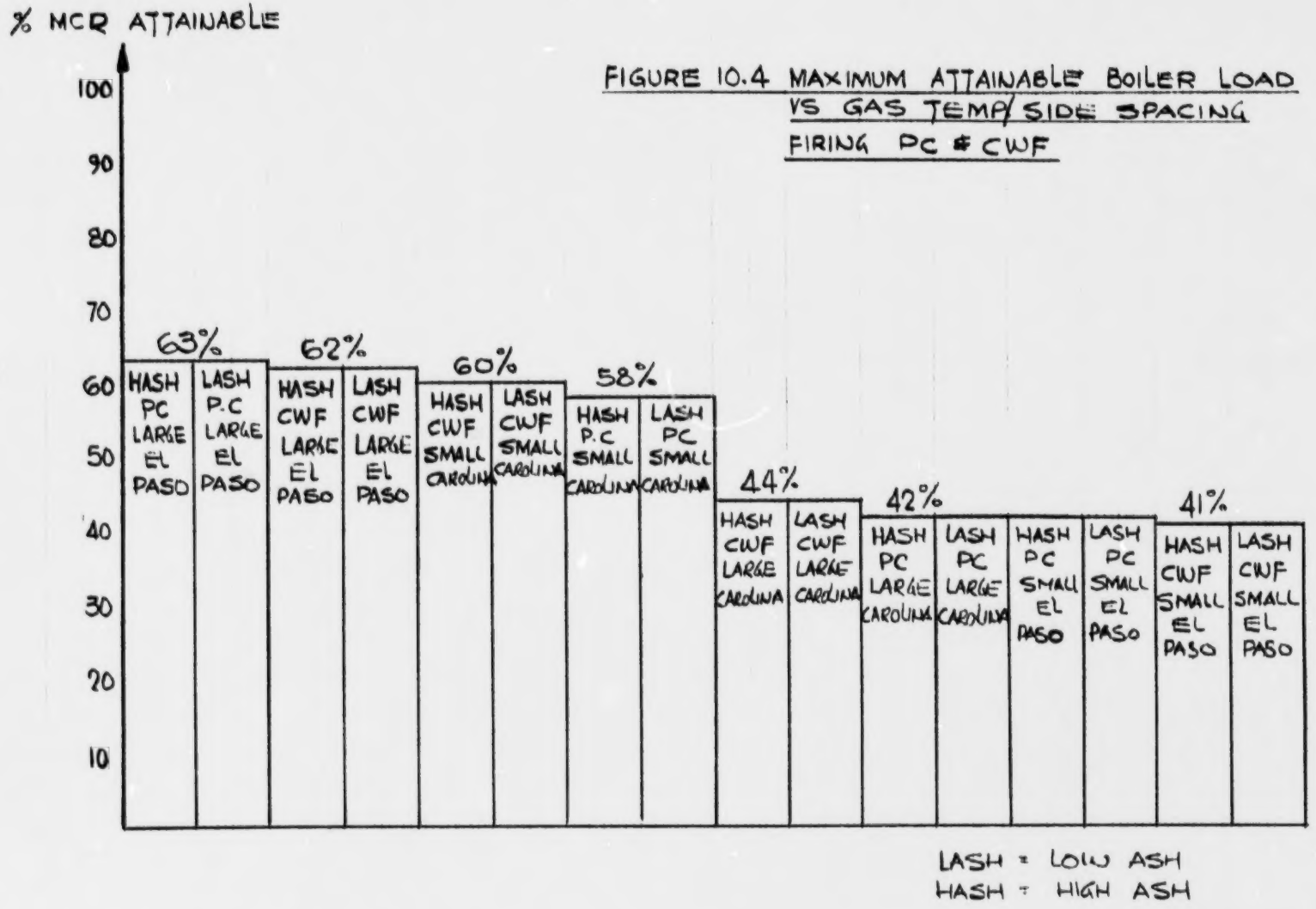

FIGURE 10.4 MAXIMUM ATTAINABLE BOILER LOAD VS GAS TEMP/SIDE SPACING FIRING PC & CWF

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